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Forest Health
Protection

Davis, CA

Bacillus thuringiensis Drift Depositions on Foliage and Physical Samplers - A Summary of the Utah Drift Studies 1991-1993

FPM 95-18
June 1995

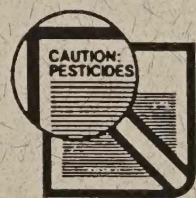
Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.



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Bacillus thuringiensis Drift Deposits on Foliage and Physical Samplers - A Summary of the Utah Drift Studies 1991-1993

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SUMMARY

This Memorandum summarizes results of the three Utah drift studies performed in late spring of the years 1991, 1992 and 1993 in the mountain canyons above Salt Lake City, Utah, as part of a gypsy moth (*Lymantria dispar L.*) eradication project. The biopesticide *Bacillus thuringiensis* var. *kurstaki* was sprayed aerially to protect stands of Gambel oak (*Quercus Gambelii* Nutt). Previous reports (Barry et al. 1993a and Teske 1995a) detail the 1991 and 1992 studies. This report re-examines the 1991 study (with new information about the spray material physical properties) and details the 1993 study. It is intended that this report form the basis of a more complete examination of the goals and objectives of the combined spray projects, to be written with the help of the enclosed statistical information.

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1. INTRODUCTION

For five consecutive years 1989 to 1993, the USDA Forest Service, in cooperation with the Utah Department of Agriculture, has been applying the biopesticide *Bacillus thuringiensis* var. *kurstaki* (Bt) to eradicate a gypsy moth infestation discovered along the west-facing exposures of the Wasatch Mountain Range, bordering the eastern edge of the Great Salt Lake Valley, above Salt Lake City, Utah. The close cooperation between these agencies, the U. S. Army Dugway Proving Ground, and others that became involved with the Bt application and analysis, provided an economic and logistical backdrop that made these drift studies practical and feasible. These studies -- in the years 1991 to 1993 -- presented an opportunity to address several questions regarding the environmental fate of biopesticides (as applied to the work summarized herein):

1. To evaluate the Wagner, Rotorod and Mylar samplers for detecting and measuring dosage, deposition and impaction (total flux) resulting from off-site movement of a biopesticide spray in mountainous terrain. The 1991 study concluded that spinning Rotorods showed less variation and were easier to use in the field than the Wagner samplers, and were therefore recommended for the succeeding studies in 1992 and 1993.

2. To evaluate whether natural foliage, such as branches of Gambel oak, could be used for detecting and measuring deposition. The 1992 study included Gambel oak foliage, as did the 1993 study, and concluded that Gambel oak foliage was a good collector for recovering deposition. The use of nonspinning Rotorods for total flux was also questioned. These recommendations were carried into the 1993 study.

3. To quantify, subject to the success of the several sampler types placed in the field, off-site movement of a biopesticide as measured from aspirated, deposition and impaction instruments. All three years attempted to answer this question, with the 1992 study reflecting -- by its relatively poor results -- the importance of reliable field instrumentation, careful recovery of field samples, and the need for a well-behaved downcanyon drainage flow and spray plume.

4. To improve the field acquisition of meteorological data, including the appropriate placement of data towers in mountainous terrain, to capture sufficient information to represent the state of the atmosphere at the time of downcanyon drift. All three study years utilized the EMCOT weather station (Ekblad, Windell and Thompson 1990), adding data from additional measuring devices (as detailed in Thistle 1993 and Teske 1995b).

5. To compare FSCBG (Forest Service Cramer-Barry-Grim) model predictions of dosage and deposition to field data, and to evaluate model performance in predicting drift of a biopesticide in mountainous terrain. FSCBG (Teske et al. 1993) has undergone extensive field testing but until the 1991 study never in a mountainous terrain condition.

Additionally, these three studies permitted researchers:

1. To investigate levels of Bt in mountain soils in the treated canyons, in cooperation with NOVO and ABBOTT Laboratories.

2. To evaluate the effects of Bt on selected non-target Lepidoptera species within the local habitat (foliage exposed to Bt in the field was fed to non-target Lepidoptera insects).

3. To evaluate the VALDRIFT model (Allwine, Bian and Whiteman 1993) developed specifically for idealized canyon topography.

This report covers that portion of the three field studies concerning:

1. Quantifying off-target movement of Bt as measured by Gambel oak foliage, aerosol, impaction and deposition samplers;

2. Comparing sampler types; and

3. Comparing FSCBG model predictions of air concentration (dosage) and deposition to observed data obtained from field samplers.

Data sources include previously reported findings for the 1991 study (Barry et al. 1993a) and the 1992 study (Teske 1995a), the 1993 meteorological data (Teske 1995b) and the 1993 work plan (Barry et al. 1993b) and dispersion data (John W. Barry, private communication). The 1991 study results will be regenerated with a corrected volatile fraction with the latest version of FSCBG (version 4.35).

2. FIELD STUDY SUMMARY

The field studies built on the experience gained in previous years toward the goal of providing a standardized set of suggestions for future USDA Forest Service environmental fate studies. Summaries of each of the three years 1991-1993 follow.

1991

The first study site was in Parley's Canyon of the Wasatch Mountain Range along Interstate 80 between Salt Lake City and Summit Park, Utah. The study is detailed in Barry et al. (1993a). Test dates were 11 June (Trial 1), 17 June (Trial 2), and 22 June (Trial 3). The receptor grid was laid from the downwind edge of the spray block along Alexander Creek to 3150 m downcanyon (with 10 sampler sites). Samplers included spinning Rotorods and Wagner samplers (for dosage), nonspinning Rotorods (for total flux); and Mylar samplers (for deposition). The spinning Rotorods were logistically easier to use than the Wagner samplers, and performed just as well; thereby making them the preferred instrument for dosage measurements.

All instruments were positioned in paired duplicates at each sampler site, as a way of assessing quality control over the recovered data. By increasing sampler density, providing duplicates, and using more than one sampler type at each sampler station, sampling process errors, incorrect sample labeling, and lost data points could be minimized. Bt was recovered throughout the sampling array downcanyon to 3150 m.

1992

The second study site was in Lamb's Canyon, which drains into Parley's Canyon. The study is detailed in Teske (1995a). Test dates were 26 May (Trial 1), 1 June (Trial 2), and 8 June (Trial 3). The receptor grid was laid from the downwind edge of the spray block along a natural drainage to 7600 m downcanyon (with 12 sampler sites). The additional distance downcanyon was an attempt to follow the spray cloud farther downwind than in the 1991 study. Samplers included spinning Rotorods (for dosage), nonspinning Rotorods (for total flux); and Mylar samplers and Gambel oak foliage (for deposition). Reynier air samplers were also used to evaluate spray plume arrival and resident times.

Several problems were encountered with the 1992 study, principally the presence of atypical winds and other atmospheric conditions that adversely affected the spray cloud, causing its main concentration to miss the sampler array. This effect, coupled with field sampler data contamination and instrument failure, meant that the second study did not achieve its goals. However, the study did show that Gambel oak foliage appears to be just as good a collector as Mylar samplers, and this information was brought forward into the third study in 1993. The 1992 study also demonstrated that Bt reached the most distant sampling station located 7600 m downwind.

1993

The third study site was in Mill Creek Canyon, south of Parley's Canyon and east of Lamb's Canyon, east of Salt Lake City, Utah. Figure 1 schematically summarizes the downcanyon geometry and the sampling grid. Test dates were 28 May (Trial 1), 4 June (Trial 2), and 10 June (Trial 3). The receptor grid was laid from the downwind edge of the spray block along the creek to 5600 m downcanyon, with 11 sampler sites at 0, 300, 900,

2000, 3000, 4000, 4250, 4500, 4800, 4800 (two separate locations at the mouth of the canyon), and 5600 m. Samplers included paired spinning Rotorods (for dosage), and paired Mylar samplers and single Gambel oak foliage (for deposition).

As before, three EMCOT weather stations were positioned along the most likely path of downcanyon off-target drift (see Figure 1 for their locations), and recovered the meteorological data for the three trials (as detailed in Teske 1995b). The tower data included: wind speed at mid-height (3.5 m) and at upper height (6.1 m); wind direction at mid-height (3.5 m) and at upper height (6.1 m); temperature at lower height (1.2 m), mid-height (3.5 m on tower 1 only), and upper height (6.1 m); relative humidity; and net radiation. Azimuthal standard deviation is recovered from one-second wind direction data by the unit vector technique (Haugen 1963). For the recorded treatment times these instruments recovered the average data shown in Table 1 (averaged over four hours from the beginning of the application time, as suggested by the persistence of the spray clouds in the 1992 study).

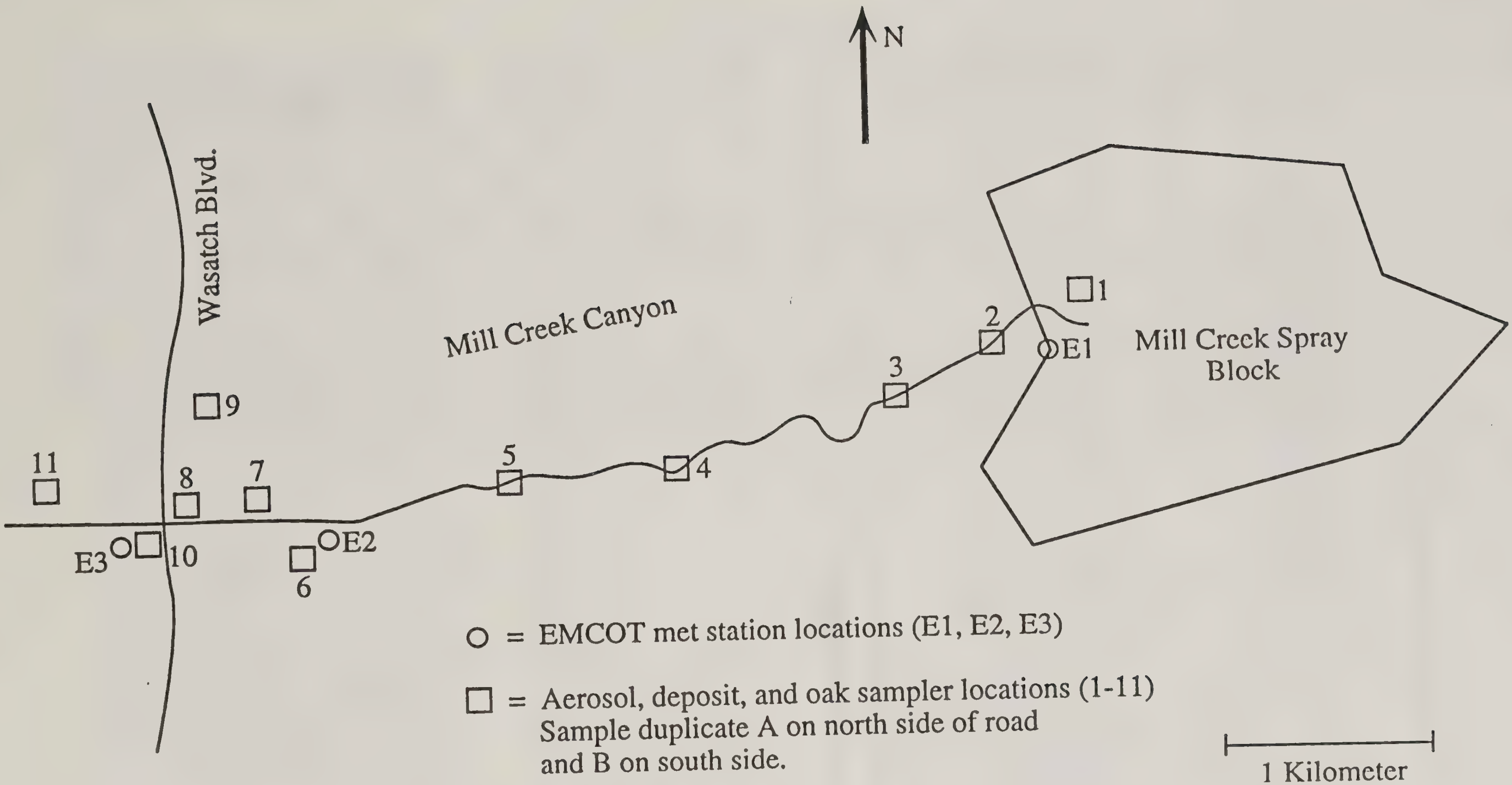

Figure 1. Schematic of the Utah 1993 Mill Creek Canyon study site.

Table 1. 1993 Utah meteorological data summary.

	Trial 1	Trial 2	Trial 3
Date	28 May 1993	4 June 1993	10 June 1993
Application Time (Begin)	5:48 am	5:47 am	5:33 am
Application Time (End)	8:19 am	8:14 am	8:48 am
EMCOT Tower 1			
Temperature (deg C) @ 1.2 m	11.73	5.49	6.75
Temperature (deg C) @ 3.5 m	11.83	5.57	7.15
Temperature (deg C) @ 6.1 m	13.14	6.44	8.37
Relative Humidity (percent)	57.01	74.30	74.88
Wind Speed (m/sec) @ 3.5 m	0.70	0.60	0.92
Wind Speed (m/sec) @ 6.1 m	0.55	0.54	0.64
Azimuthal Standard Deviation (rad) @ 3.5 m	0.2751	0.2816	0.2557
Azimuthal Standard Deviation (rad) @ 6.1 m	0.3726	0.3604	0.3570
EMCOT Tower 2			
Temperature (deg C) @ 1.2 m	16.28	9.56	12.69
Temperature (deg C) @ 6.1 m	16.62	9.60	13.23
Relative Humidity (percent)	36.47	45.71	40.51
Wind Speed (m/sec) @ 3.5 m	-	-	0.91
Wind Speed (m/sec) @ 6.1 m	2.14	1.13	1.32
Azimuthal Standard Deviation (rad) @ 6.1 m	0.5824	0.7614	0.6582
EMCOT Tower 3			
Temperature (deg C) @ 1.2 m	17.54	10.50	13.84
Temperature (deg C) @ 6.1 m	17.47	10.42	13.75
Relative Humidity (percent)	38.14	46.33	42.26
Wind Speed (m/sec) @ 3.5 m	1.54	1.62	2.12
Wind Speed (m/sec) @ 6.1 m	1.67	1.77	2.42
Azimuthal Standard Deviation (rad) @ 3.5 m	0.5767	0.6393	0.5065
Azimuthal Standard Deviation (rad) @ 6.1 m	0.4929	0.5985	0.4419

3. SAMPLER STATISTICS

To examine the accuracy of the field data, we first examine how closely each sampler pair recover the same readings, then explore the relationship across sampler types. To do this we use well-established statistical techniques (as discussed below) for examining experimental data, then draw conclusions based upon a comparison across the three studies.

Consistency Among Paired Duplicates

To evaluate the consistency in sampler performance for each of the three trials in each of the three studies, we first calculate the relative standard deviation (RSD) of the measurements by sampler type. In theory each sampler pair at each sampling station should recover the same amount of the passing spray cloud. In truth, because this is the real world, paired sampling stations at the same downcanyon distance will generally give different results, depending on the actual spray cloud position and concentration as it moves downcanyon.

The equation used to compute RSD is

$$RSD = \frac{1}{\overline{D}}\left[\frac{1}{N}\sum\left(D_i - \overline{D}\right)^2\right]^{1/2} \tag{1}$$

where

$$\overline{D} = \frac{1}{N}\sum D_i \tag{2}$$

is the average value of dosage, deposition or total flux levels D_i. The index i denotes each data entry, and N denotes the total number of data points considered. The results of applying Eqs 1 and 2 to the 1993 sampler data are summarized in Table 2 (the results from 1991 and 1992 are included for comparison).

A set of data well-approximated by its average value at each downcanyon distance might have an RSD value as high as 0.1 (perfect data correlation would give an RSD of 0.0; a value of 0.1 suggests that the data variation is ten percent of the data average). The data in Table 2 illustrates that the 1991 study was without question the best study with regard to consistent data. The 1992 study showed a significant increase in data errors (as represented by the combined RSD values), while the 1993 study showed a smaller combined RSD value for the spinning Rotorods (as in the 1992 study), and a combined RSD value closer to the smaller 1991 study value for Mylar samplers. The ability to replicate data recovery at paired sensors is likely not a function of spray cloud behavior, since each duplicate pair was in close proximity. Rather, any data errors are more likely the result of field crew handling errors, instrument inoperability, battery failure (for the spinning Rotorods), and/or sample contamination. It is most unfortunate that the Gambel oak foliage in the 1993 study was not paired, even though that was the intent in the work plan (Barry et al. 1993b). With the additional data we would have hopefully seen a decrease in the combined RSD value from the 1992 study, thereby enhancing the usefulness of foliage as a collector.

As a matter of record, the smaller combined RSD value (and the smaller values for each 1991 trial) for spinning Rotorods compared with Wagner samplers led to the removal of Wagner samplers in the later studies. Because the computer model does not predict total flux, the nonspinning Rotorods were also removed in the 1993 study. Even though the 1992 combined RSD values are high for both Mylar samplers and Gambel oak foliage, their nearly equal values (0.489 vs 0.506 respectively) indicate that natural foliage may be a useful deposition collector that can be used with some confidence.

Correlation Among Sampler Types

We next calculate the correlation among sampler types by computing the linear least squares through the averaged sampler data at each downcanyon station. Even though samplers may not necessarily be well-correlated by sampler type (as shown in Table 2), their average values will still correlate from sampler type to sampler type. We assume that the correlation may be approximated by the straight line

$$\hat{Y}_i = a\,X_i + b \tag{3}$$

where a is the slope of the line, b is its vertical intercept and X_i is any i average value for the first sampler type compared. We minimize the least-squares error

$$E = \sum [Y_i - a\,X_i - b]^2 \tag{4}$$

where Y_i is any i average value for the second sampler type compared. The correlation coefficient may then be defined by

$$R^2 = \frac{\sum[\hat{Y}_i - \overline{Y}]^2}{\sum[Y_i - \overline{Y}]^2} \tag{5}$$

where

$$\overline{Y} = \frac{1}{N}\sum Y_i \tag{6}$$

is the average value. The results of applying Eqs 3 to 6 to the 1993 study are summarized in Table 3 (the results from 1991 and 1992 are included for comparison).

A correlation coefficient above 0.9 is generally considered good, meaning here that the straight-line fit accounts for 90 percent of the variance in the data (the maximum value for correlation coefficient is 1.0). Because the data span such a wide range in values, we choose to examine the data logarithmically. The data in Table 3 show that the best correlations were observed between spinning Rotorods and all other sampler types, for all three studies. The spinning Rotorods, Wagner samplers and nonspinning Rotorods were well correlated with each other, which is why the Wagner samplers were discontinued in the 1992 and 1993 studies. The nonspinning Rotorods correlated reasonably well with the

Gambel oak foliage in 1992, and with the spinning Rotorods in 1991 and 1992, which is also why the nonspinning Rotorods were discontinued in the 1993 study. And, finally, the Mylar samplers (positioned horizontally close to the ground) and the Gambel oak foliage (suspended above the ground) were less well correlated, which suggests that they are measuring different deposition effects.

Table 3 shows that data from the Spinning Rotorods and Wagner Samplers were measured in cfu-min/L, data from the Nonspinning Rotorods were measured in cfu, and data from the Mylar Samplers and Gambel Oak Foliage were measured in cfu/cm^2. In the three studies described here, cfu refers to Bt colony forming units. Dosage sampling rate was 120 L of air per minute, which suggests that a person standing at a sampling station would inhale cfu's at the measured dosage level (summarized in Section 6) multiplied by 120.

A comparison of correlation coefficients for all three studies reveals the following five observations:

1. The spinning Rotorods vs nonspinning Rotorods were well correlated in both the 1991 study (0.935) and the 1992 study (0.734), suggesting that one of the sampler types was unnecessary (the nonspinning Rotorods were removed in the 1993 study).

2. The spinning Rotorods vs Mylar samplers were well correlated in the 1991 study (0.812) and the 1993 study (0.731), but very poorly correlated in the 1992 study (0.010). The accuracy of the spinning Rotorod data in the 1992 study has therefore been questioned (Teske 1995a).

3. The nonspinning Rotorods vs Mylar samplers were well correlated in the 1991 study (0.877) and poorly correlated in the 1992 study (0.044). Here, sample contamination and poor field practices have been suggested (Teske 1995a).

4. The spinning Rotorods vs Gambel oak foliage were somewhat correlated in the 1992 study (0.492) and less correlated in the 1993 study (0.288). Since the 1992 spinning Rotorod data has been questioned, these results may suggest that dosage and deposition collectors do not correlate well, and perhaps they should not.

5. Surprisingly, the Mylar samplers vs Gambel oak foliage were somewhat correlated in the 1992 study (0.360) and less correlated in the 1993 study (0.193), for reasons that are presently unclear.

Plots of the three 1993 correlations are given in Figures 2 to 4. The slopes of the logarithmic least squares straight lines are between 0.4 and 0.6, with the comparisons between the spinning Rotorods and Mylar samplers the best correlated. Overall correlations for all samplers were good in the 1991 study, quite poor in the 1992 study and somewhat better in the 1993 study. Because the sampler pairs were in close proximity to each other, errors seen here must be attributed to the typical level of errors expected in field operations, the accuracy of the measuring devices, handling of field samples, and/or the care taken in sample recovery and interpretation.

Table 2. Relative standard deviation at paired duplicate sampling stations for each type of sampler.

Year	Sampler Type	Trial 1	Trial 2	Trial 3	Combined
1991	Spinning Rotorods	0.143	0.174	0.196	0.172
	Wagner Samplers	0.236	0.312	0.319	0.291
	Nonspinning Rotorods	0.196	0.391	0.316	0.326
	Mylar Samplers	0.250	0.224	0.121	0.206
1992	Spinning Rotorods	0.273	0.388	0.454	0.377
	Nonspinning Rotorods	0.451	0.587	0.543	0.515
	Mylar Samplers	0.205	0.555	0.611	0.489
	Gambel Oak Foliage	0.500	0.523	0.498	0.506
1993	Spinning Rotorods	0.299	0.346	0.425	0.349
	Mylar Samplers	0.192	0.258	0.332	0.257
	Gambel Oak Foliage		... duplicate only ...		

Table 3. Statistical comparisons of sampler type, logarithmic least squares slope and intercept, and correlation coefficient, combined over all three trials of each study year (cfu refers to Bt colony forming units).

Year	Sampler Type	Slope	Intercept	R^2
1991	Spinning Rotorods (cfu-min/L) vs Wagner Samplers (cfu-min/L)	0.535	1.255	0.779
	Spinning Rotorods (cfu-min/L) vs Nonspinning Rotorods (cfu)	0.987	1.092	0.935
	Spinning Rotorods (cfu-min/L) vs Mylar Samplers (cfu/cm^2)	1.469	-2.602	0.812
	Wagner Samplers (cfu-min/L) vs Nonspinning Rotorods (cfu)	1.502	-0.123	0.672
	Wagner Samplers (cfu-min/L) vs Mylar Samplers (cfu/cm^2)	1.851	-2.859	0.590
	Nonspinning Rotorods (cfu) vs Mylar Samplers (cfu/cm^2)	1.396	-6.674	0.877
1992	Spinning Rotorods (cfu-min/L) vs Nonspinning Rotorods (cfu)	0.701	2.329	0.734
	Spinning Rotorods (cfu-min/L) vs Mylar Samplers (cfu/cm^2)	0.097	2.337	0.010
	Spinning Rotorods (cfu-min/L) vs Gambel Oak Foliage (cfu/cm^2)	0.459	2.327	0.492
	Nonspinning Rotorods (cfu) vs Mylar Samplers (cfu/cm^2)	0.191	1.495	0.044
	Nonspinning Rotorods (cfu) vs Gambel Oak Foliage (cfu/cm^2)	0.664	-0.570	0.680
	Mylar Samplers (cfu/cm^2) vs Gambel Oak Foliage (cfu/cm^2)	0.628	1.498	0.360
1993	Spinning Rotorods (cfu-min/L) vs Mylar Samplers (cfu/cm^2)	0.451	2.383	0.731
	Spinning Rotorods (cfu-min/L) vs Gambel Oak Foliage (cfu/cm^2)	0.391	2.927	0.288
	Mylar Samplers (cfu/cm^2) vs Gambel Oak Foliage (cfu/cm^2)	0.588	1.842	0.193

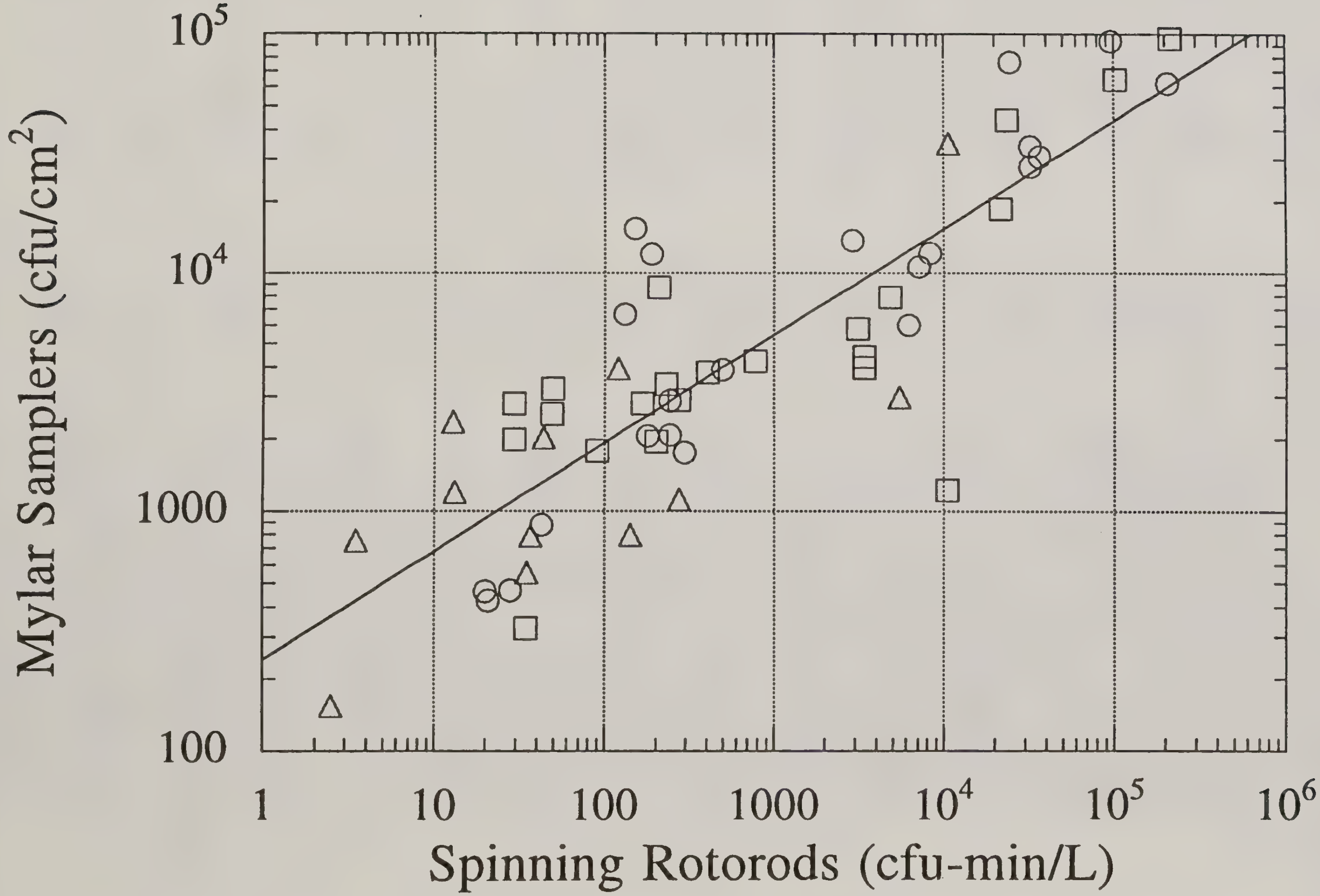

Figure 2. 1993 Utah study -- comparison between average spinning Rotorods and Mylar samplers at all downcanyon sampling stations: Trial 1 data are denoted by circles; Trial 2 data by squares; and Trial 3 data by triangles. The solid line is the logarithmic least-squares straight line through the data, with a correlation coefficient of 0.731.

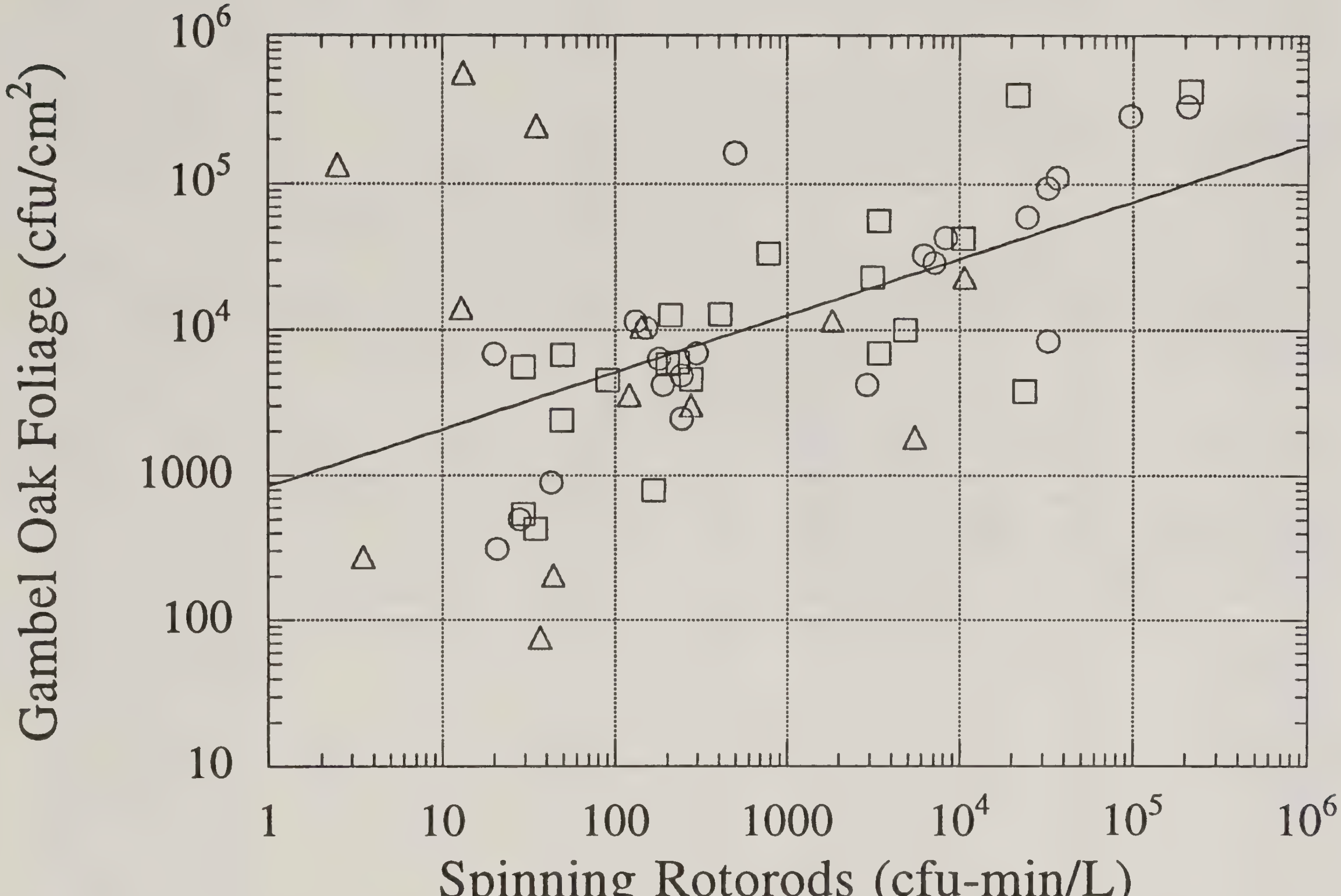

Figure 3. 1993 Utah study -- comparison between average spinning Rotorods and Gambel oak foliage at all downcanyon sampling stations: Trial 1 data are denoted by circles; Trial 2 data by squares; and Trial 3 data by triangles. The solid line is the logarithmic least-squares straight line through the data, with a correlation coefficient of 0.288.

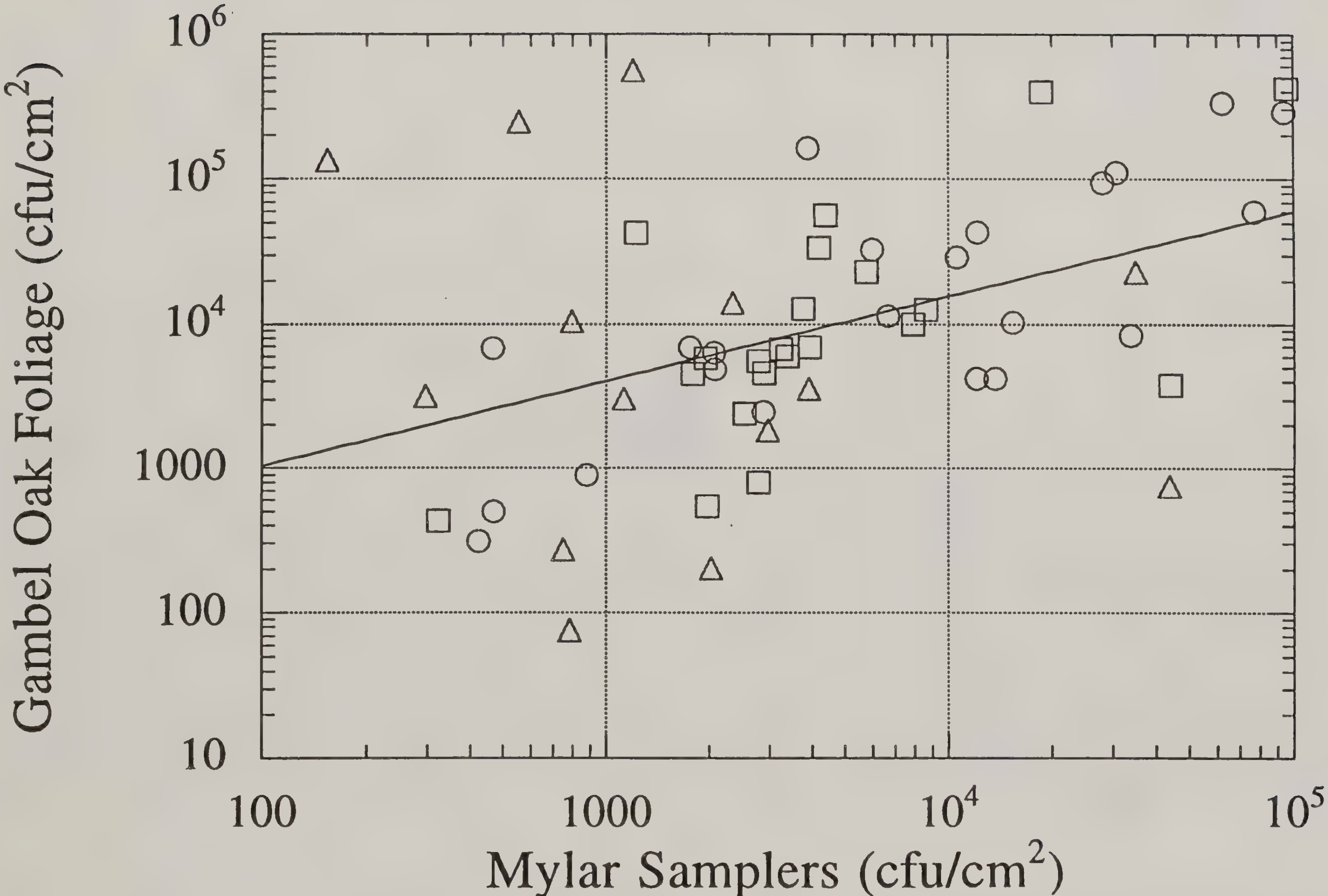

Figure 4. 1993 Utah study -- comparison between average Mylar samplers and Gambel oak foliage at all downcanyon sampling stations: Trial 1 data are denoted by circles; Trial 2 data by squares; and Trial 3 data by triangles. The solid line is the logarithmic least-squares straight line through the data, with a correlation coefficient of 0.193.

4. FSCBG MODEL COMPARISONS

Although the sampler data were not especially well-correlated, the test data were sufficient to exercise the FSCBG model and make comparisons of field recoveries to FSCBG model predictions. A revised volatile fraction of the Bt spray material requires us to re-examine our predictions for the 1991 study (in Section 5) and enables us to make predictions for the 1993 study (in this section). As before, this process demonstrates the need for good test design and field practice, and understanding atmospheric behavior of spray clouds in complex terrain conditions, especially when conducting field to model comparisons.

Model Inputs

Inputs to FSCBG were consistent across all three study years. Specifically, these assumptions included the following:

1. Receptor Grid. A grid was laid out in the X direction, positive downcanyon with X = 0 at the downwind edge of the spray block. The last sampling station was positioned 3150 m downcanyon (in the 1991 study), 7600 m downcanyon (in the 1992 study) and 5600 m downcanyon (in the 1993 study). To compensate for the anticipated source lines to cover the spray block, the receptor grid was extended to 7920 m (in the 1991 study), 12474 m (in the 1992 study) and 7600 m (in the 1993 study). In this way the final downcanyon sampler location would still be predicted by the most upcanyon flight line, and data extrapolation would be unnecessary.

2. Aircraft. An aircraft used consistently in the three spray projects was the Bell Jet Ranger III weighing 989.3 kg, with a rotor diameter of 10.17 m and a blade rotation rate of 384 rpm (all aircraft data from the FSCBG library).

3. Spray System Geometry. Four Beecomist 360A nozzles were positioned horizontally (measured from the helicopter centerline with positive numbers to the right of the pilot) and vertically (measured from the rotor plane downward as negative numbers) of

Horizontal (m)	Vertical (m)
-4.01	-3.20
-1.92	-3.20
1.78	-3.20
3.95	-3.20

4. Spray Material. Undiluted Bt, sprayed in the three studies, were Foray 48B (in the 1991 study), Thuricide 48LV (in the 1992 study) and Dipel 6AF (in the 1993 study). Each product was labeled to contain 48 billion international units per gallon, or 13200 international units of potency per milligram. For the 1991 and 1993 studies the Bt is assumed to have a specific gravity of 1.16 and a volatile fraction of 0.6 (in the 1992 study the Bt was assumed to have a specific gravity of 1.14 and a volatile fraction of 0.6 as well). A consistent mass size distribution for the 1991 and 1993 studies (obtained from the FSCBG library) is

Average Drop Diameter (µm)	Mass Fraction
16.45	0.0002
28.72	0.0005
43.00	0.0016
59.54	0.0047
78.65	0.0126
100.73	0.0297
126.20	0.0604
155.62	0.1046
189.57	0.1545
228.75	0.1888
273.97	0.1852
326.17	0.1394
386.40	0.0784
455.93	0.0302
536.16	0.0077
628.76	0.0014

The above drop size distribution was expanded by interpolation (within the FSCBG program) so that no drop category contained more than two percent of the mass fraction (Teske and Curbishley 1994). This step resulted in 60 drop size categories. The 1992 study assumed a slightly different drop size distribution (Teske 1995a).

5. Source Geometry. We assume that the aircraft flew at a spraying speed of 31.3 m/sec and a release height of 22.85 m. The emission rate was 4.68 L/ha (0.5 gal/ac). The swath width is assumed to be 30.5 m. Since the spray block was approximately 2000 m deep (in the 1993 study), we needed to simulate spraying from 66 flight lines. To accomplish this most efficiently, FSCBG was run for one flight line and the program COMBINE (Teske 1995c) was used to overlap the effects of the rest of the flight lines upcanyon at the downcanyon distances where samplers were located. The 1991 study required overlapping 121 flight lines, while the 1992 study required overlapping 118 flight lines.

6. Meteorology. The altitude at the spray site translated into an ambient pressure of 828 mb. The early morning spraying inferred a net radiation index of 1.0. Wind direction must be assumed constant, and was taken downcanyon throughout the simulation of the three trials in the 1993 study. All other parameters were averaged from Table 1 to give

	Trial 1	Trial 2	Trial 3
Temperature (deg C)	15.46	8.67	11.44
Relative Humidity (percent)	43.87	55.45	52.55
Wind Speed (m/sec) @ 6.1 m	1.45	1.15	1.46
Azimuthal Standard Deviation (rad)	0.4826	0.5734	0.4857

7. Dispersion Results. Volume units were predicted by FSCBG: dosage in cm^3-min/m^3 and deposition in cm^3/m^2 for the nonvolatile spray material collected. Laboratory analyses found an average of 7.3 billion colony forming units (cfu) per milliliter (for the

1991 study), 11.7 billion cfu per milliliter (for the 1992 study) and 178.0 billion cfu per milliliter (for the 1993 study). These conversion factors multiply the FSCBG predictions to recover dosage and deposition in the units needed to compare with data.

Model Results

Dosage comparisons for the three trials in the 1993 study are shown in Figures 5 to 7, while deposition comparisons are given in Figures 8 to 10. The dosage predictions show very good agreement with the field data from the downwind edge of the spray block to perhaps 3 km downcanyon (especially in Trials 1 and 2). At this point the model predictions tend to level off, while the data falls more rapidly. Some of the sampler locations were off to the side of the canyon, as shown in Figure 1, and may account for some of the data scatter. Another possible reason is variability in plume time and concentration, due to changes in release elevation, atmospheric conditions, and time of morning. The steep terrain may simply have prevented the spray cloud from touching down to the samplers (particularly in Trial 3). Additionally, trees present along the sides of the canyon (and not included in the simulation) could have scavenged the spray cloud. In the 1991 study Parley's Canyon was quite open and sparse of trees (and FSCBG made its best comparisons with data), while here in Mill Creek the canyon walls were forested and V-shaped.

For convenience we have assumed that the collecting devices are 100 percent efficient. If this assumption were incorrect, the dosage levels (and deposition levels to follow) should be reduced. Unfortunately, that would reduce the dosage level at the downwind edge of the spray block and out to 3 km, which we do not wish to do. Thus, something other than collector efficiency is at play here.

Nonetheless, it would appear from the dosage plots that the flat terrain prediction by FSCBG is valid much farther downcanyon than we would have initially suspected. A real test of the VALDRIFT model is whether the canyon topography can recover the dosage levels at 4 to 6 km downcanyon. It is our understanding that such a comparison is presently underway (Harold W. Thistle Jr., private communication).

Similar results are obtained for deposition, as shown in Figures 8 to 10. While we are able to predict deposition levels comparable to the field data at the downwind edge of the spray block, the prediction quickly drops to levels of up to one order of magnitude below the data (out to 3 km), before recovering levels consistent with the field data (4 to 6 km downcanyon). In this case Trial 3 presents the best agreement from the spray block to 6 km downcanyon. The non-target Lepidoptera data scatters around the FSCBG predictions as well. It is our belief that a complex terrain model such as VALDRIFT will concentrate the deposition somewhat in the intermediate distance downcanyon, and may in fact better predict the 1993 field data. Overall, however, given the many variables present in the 1993 field study, and the assumptions we have had to make to run the model, these results are rather satisfying.

The corresponding statistical comparisons between sampler types and FSCBG predictions are given in Table 4 (the 1991 and 1992 results are included for comparison) and plotted in Figures 11 to 13. Table 4 illustrates how accurately the model compared with the 1991 field data (represented by the correlation coefficient), how poorly the comparison was with the 1992 field data (because the spray cloud did not traverse the valley center, Teske 1995a), and how well the model recovered with the 1993 field data (except for the Gambel oak foliage comparison). The 1993 comparison between dosage and spinning Rotorods (Figure 11), and deposition and Mylar samplers (Figure 12), are

especially good. The FSCBG dosage and deposition levels appear bunched up (at 8000 cfu-min/L in Figure 11, and 2000 cfu/cm^2 in Figures 12 and 13) because the FSCBG predictions level off after 3 km downcanyon.

Finally, if we compare FSCBG predictions to the average dosage or deposition values at each sampler station, we recover the relative standard deviation between the data and the predictions (Table 5), and the least squares slope between the data and the predictions (Table 6). The 1991 and 1992 results are included for comparison.

These two tables clearly show that the 1992 study was flawed in comparison to the 1991 and 1993 studies. RSD values (Table 5) were higher in the 1992 study than the other two years, and the least squares slopes (which should be close to 1.0 for agreement between data and predictions) were generally higher. It is interesting to note that the model overpredicts in certain circumstances and underpredicts in others, but in general represents the effects happening in the field. If all data for the three study years and the three trials in each study were averaged, the least squares slope for dosage becomes 4.16 (overpredicting by just over a factor of 4), and for deposition becomes 2.33 (overpredicting by just over a factor of 2). One might postulate that the overprediction could be attributed to effects of complex terrain.

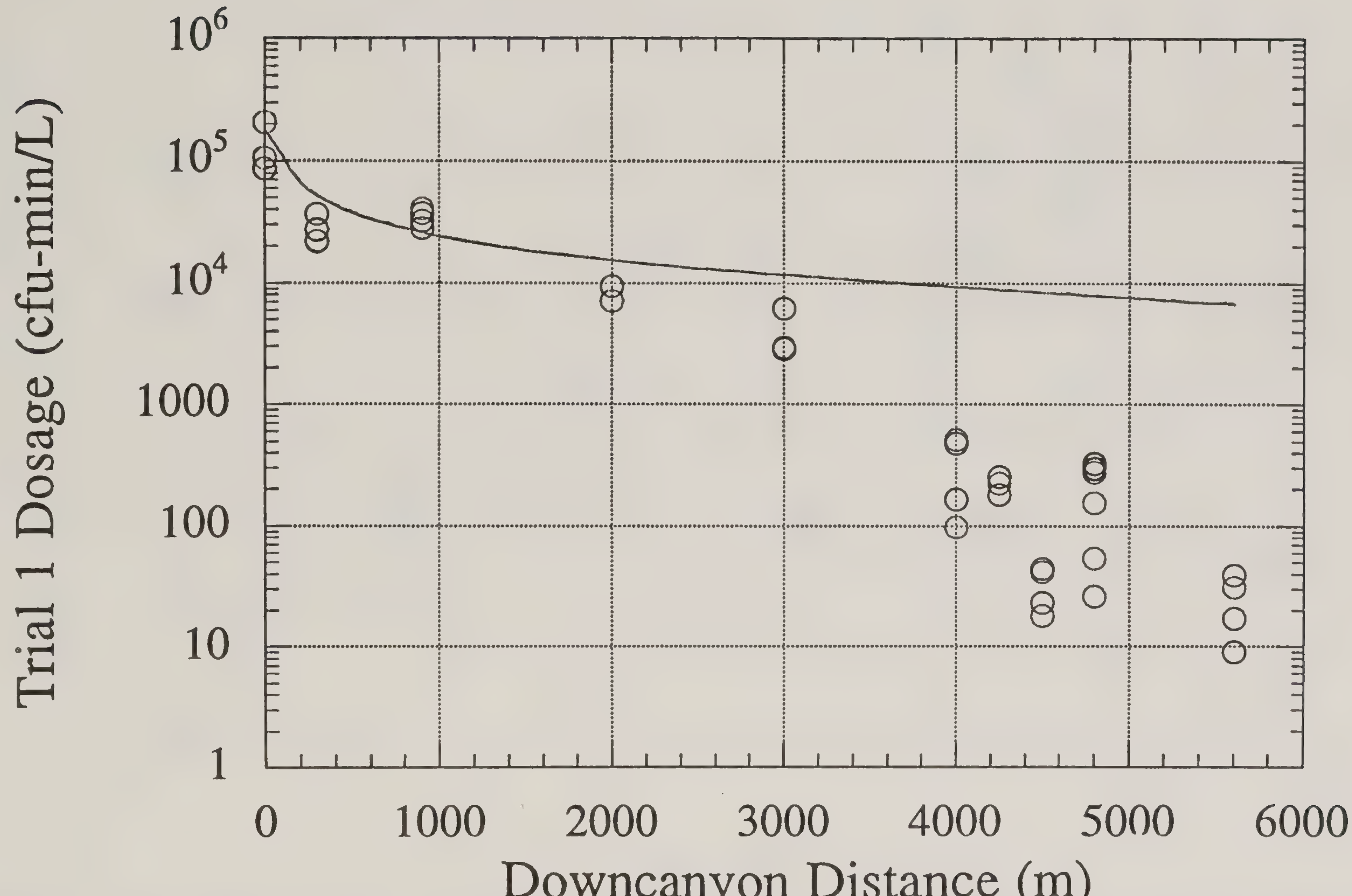

Figure 5. 1993 Utah study Trial 1 -- downcanyon distance comparison between dosage data (spinning Rotorods -- circles) and prediction (FSCBG -- solid line).

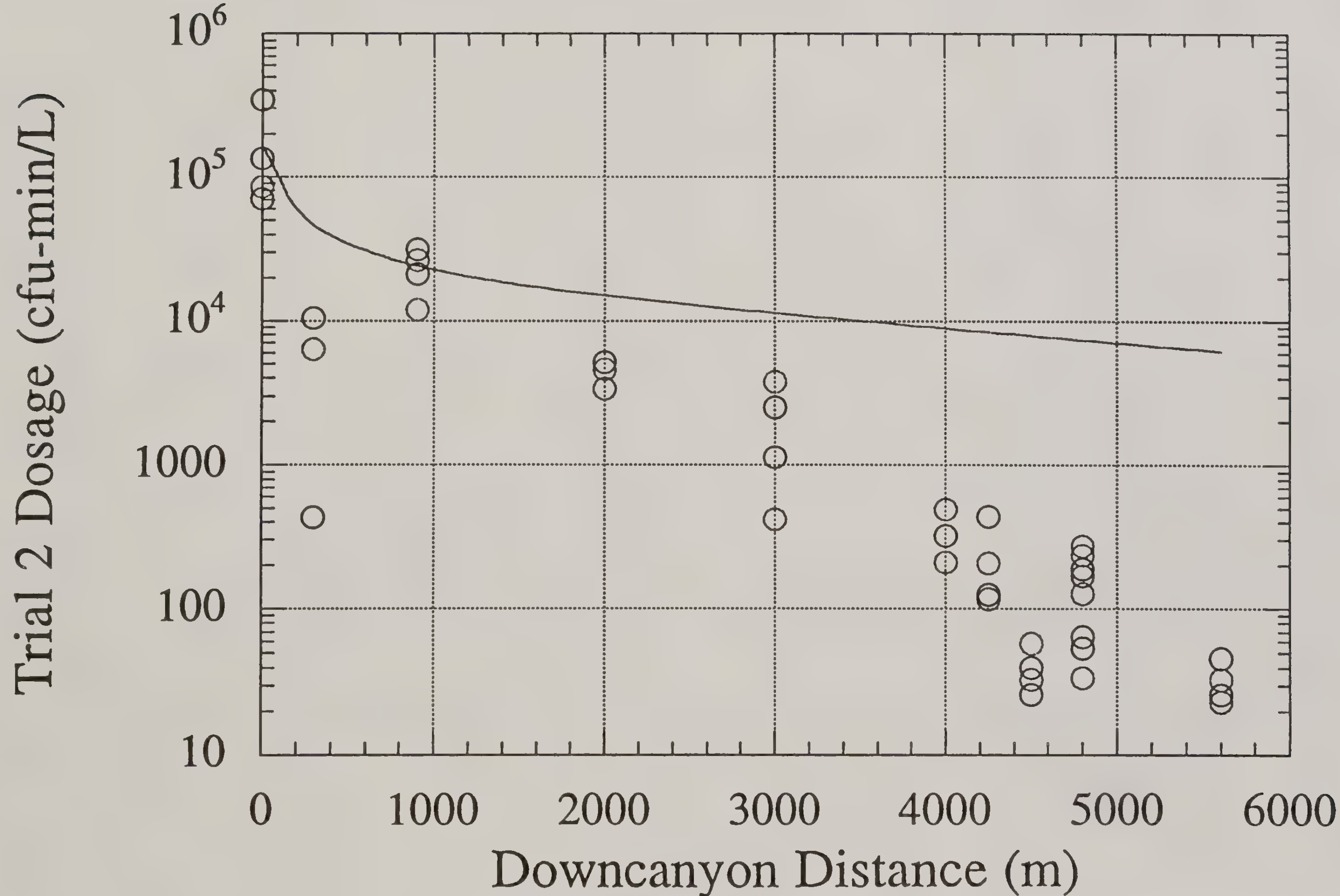

Figure 6. 1993 Utah study Trial 2 -- downcanyon distance comparison between dosage data (spinning Rotorods -- circles) and prediction (FSCBG -- solid line).

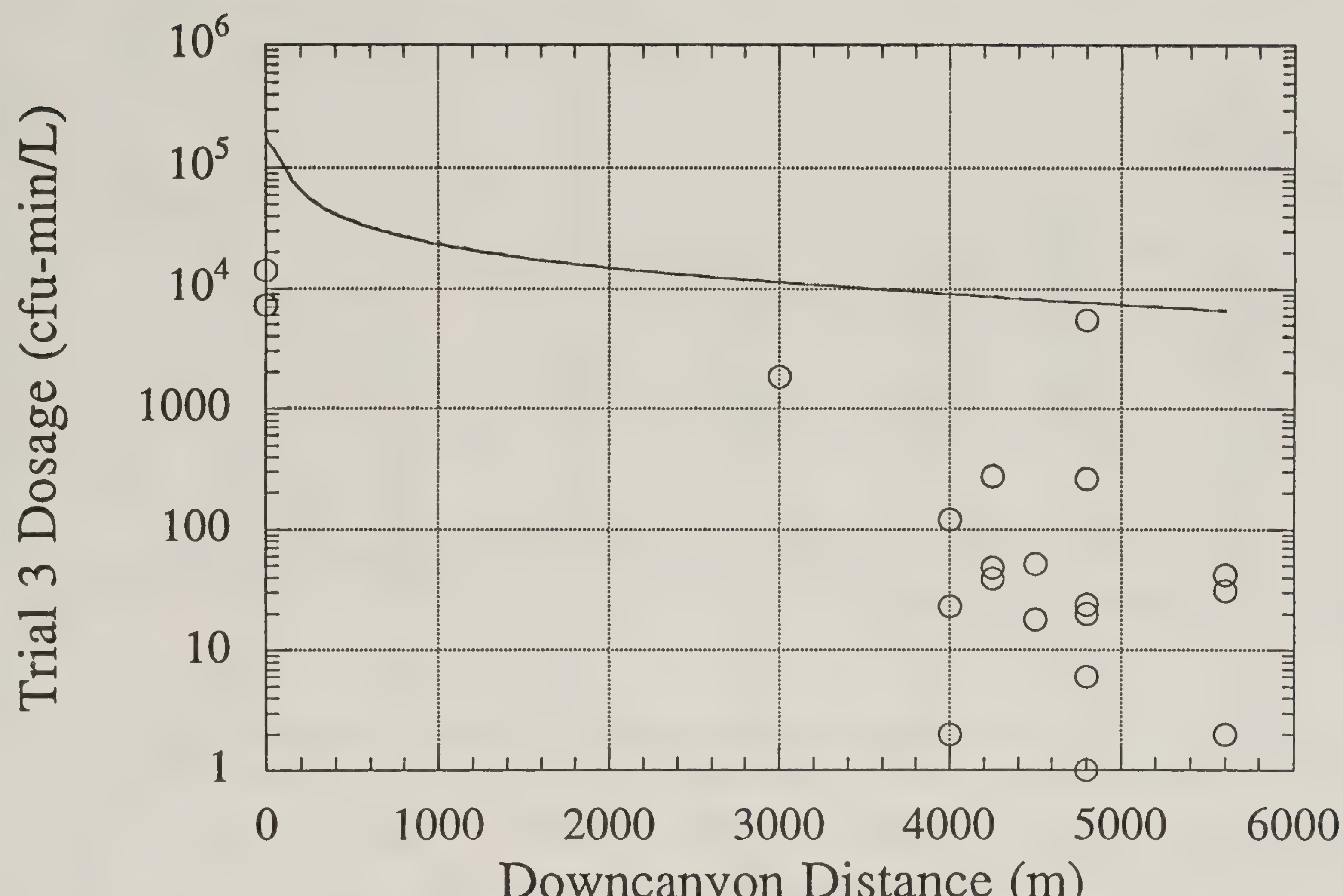

Figure 7. 1993 Utah study Trial 3 -- downcanyon distance comparison between dosage data (spinning Rotorods -- circles) and prediction (FSCBG -- solid line).

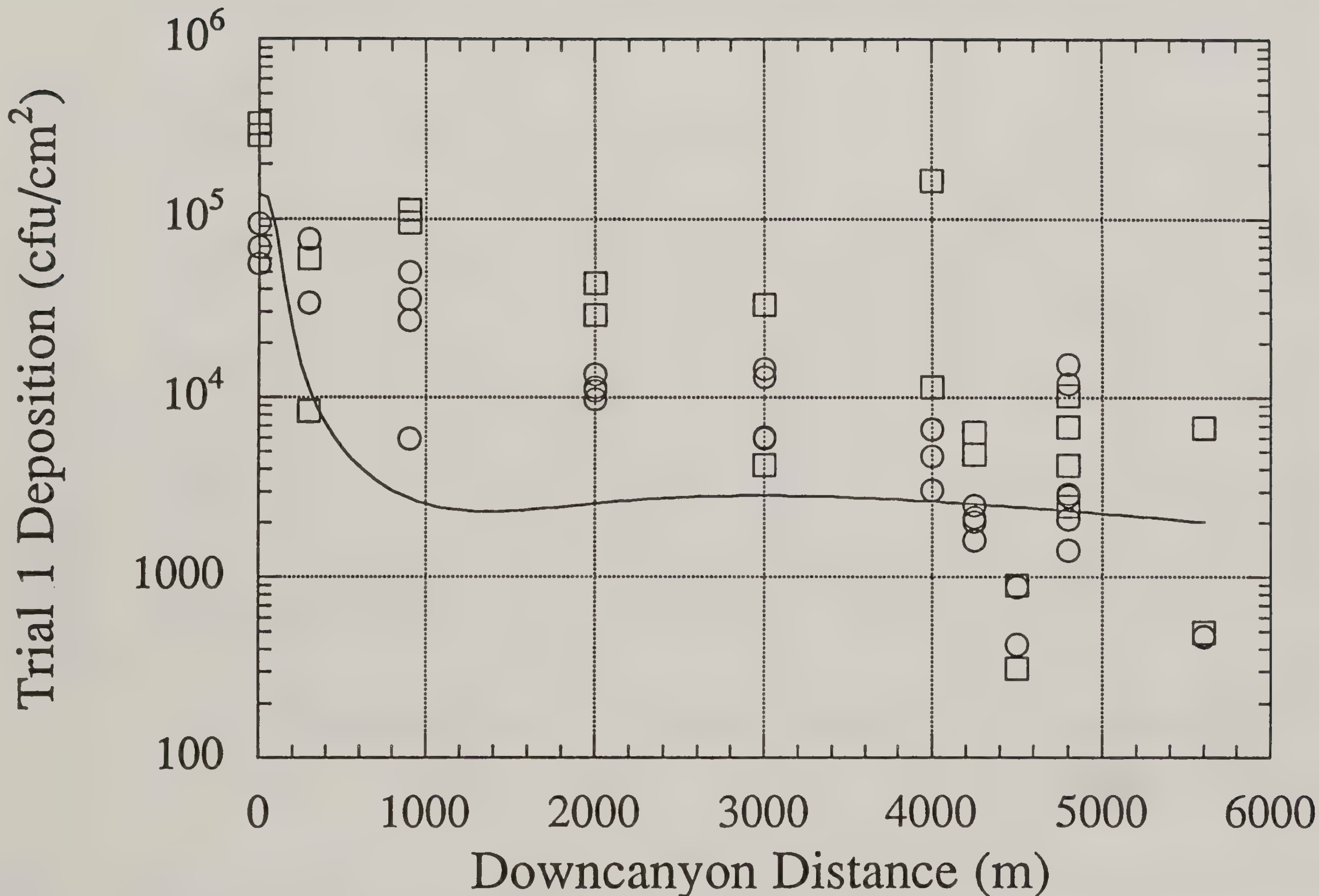

Figure 8a. 1993 Utah study Trial 1 -- downcanyon distance comparison between deposition data (Mylar samplers -- circles; Gambel oak foliage -- squares) and prediction (FSCBG -- solid line).

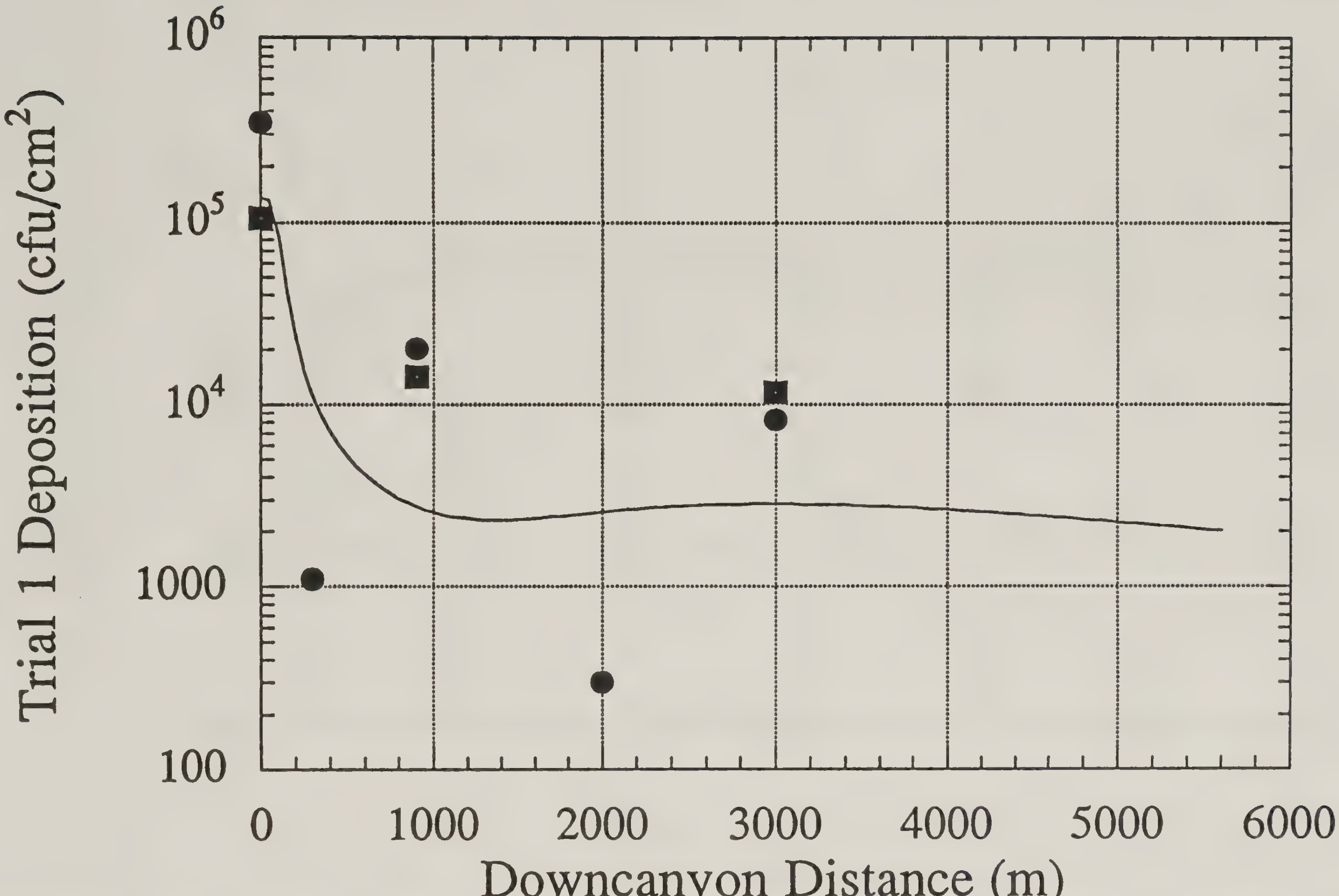

Figure 8b. 1993 Utah study Trial 1 -- downcanyon distance comparison between deposition data (cliffrose -- circles; buckwheat -- squares) and prediction (FSCBG -- solid line).

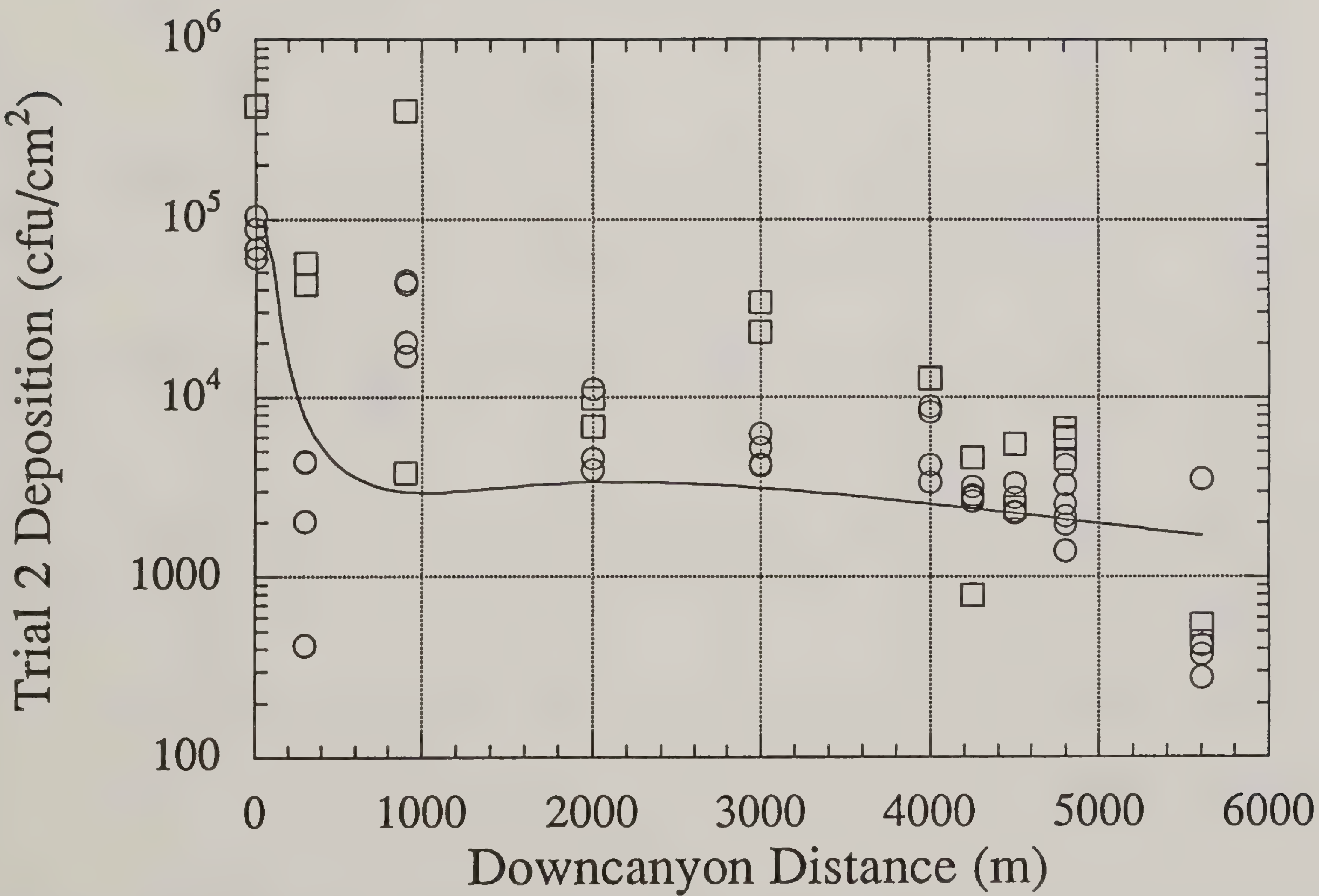

Figure 9a. 1993 Utah study Trial 2 -- downcanyon distance comparison between deposition data (Mylar samplers -- circles; Gambel oak foliage -- squares) and prediction (FSCBG -- solid line).

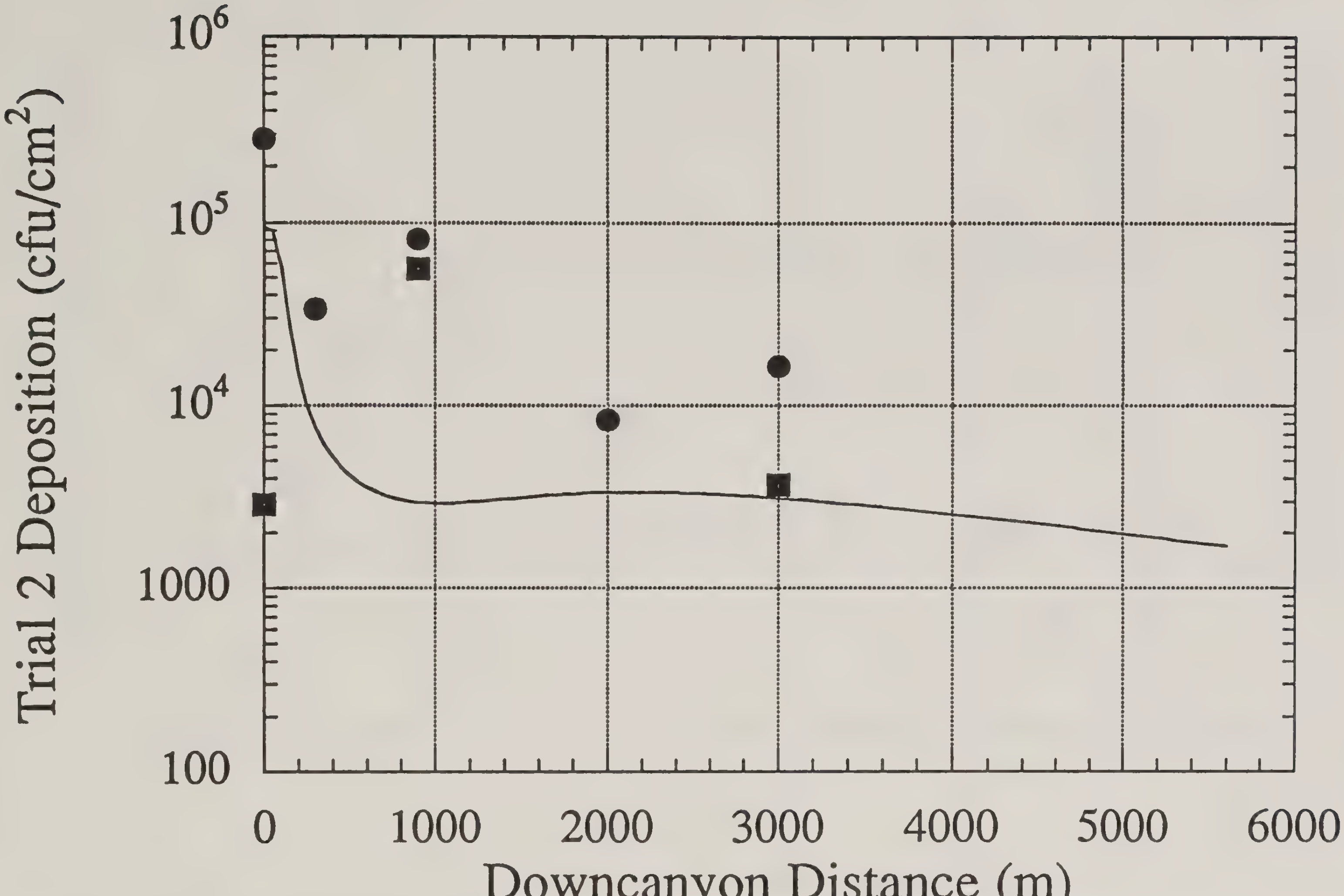

Figure 9b. 1993 Utah study Trial 2 -- downcanyon distance comparison between deposition data (cliffrose -- circles; buckwheat -- squares) and prediction (FSCBG -- solid line).

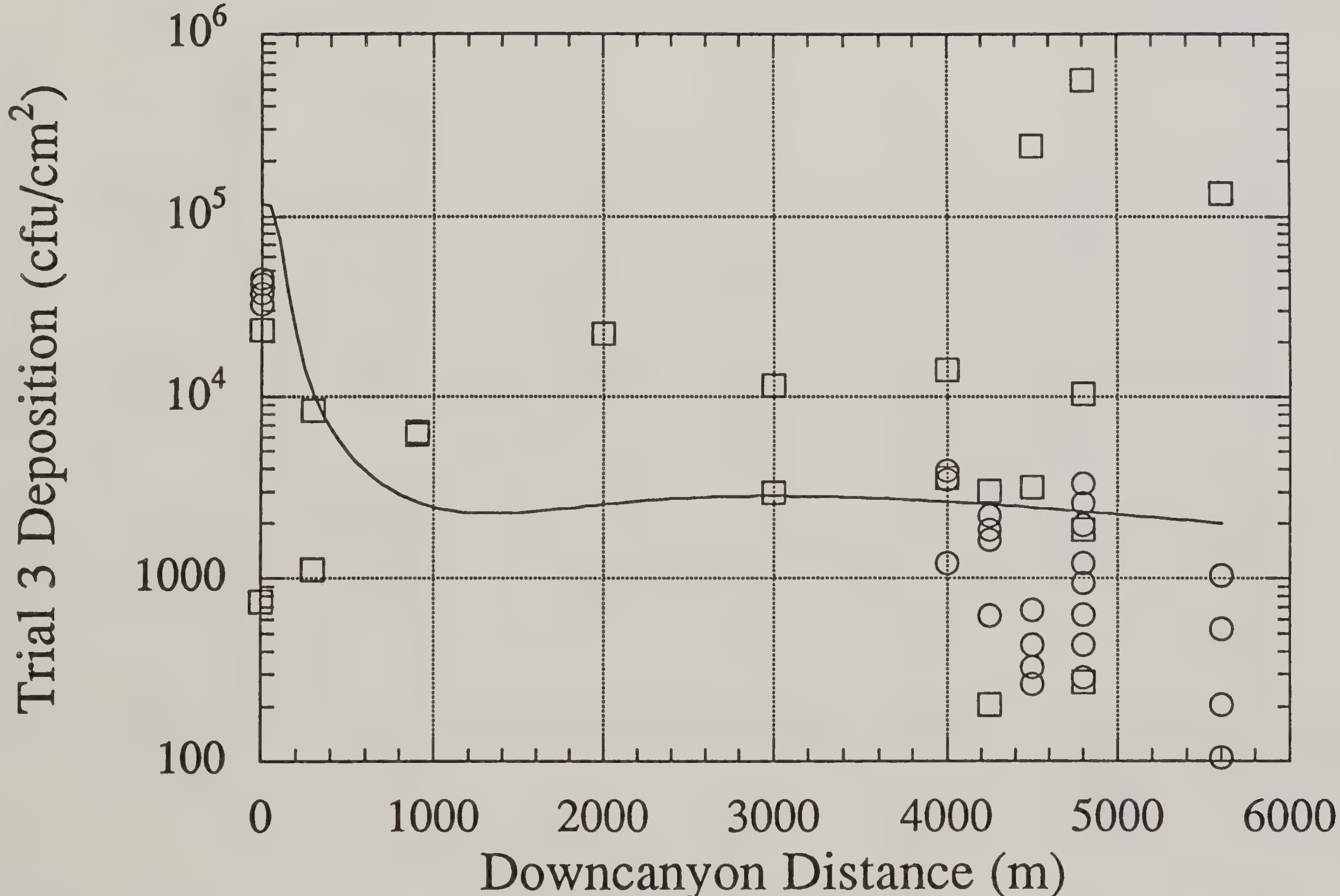

Figure 10a. 1993 Utah study Trial 3 -- downcanyon distance comparison between deposition data (Mylar samplers -- circles; Gambel oak foliage -- squares) and prediction (FSCBG -- solid line).

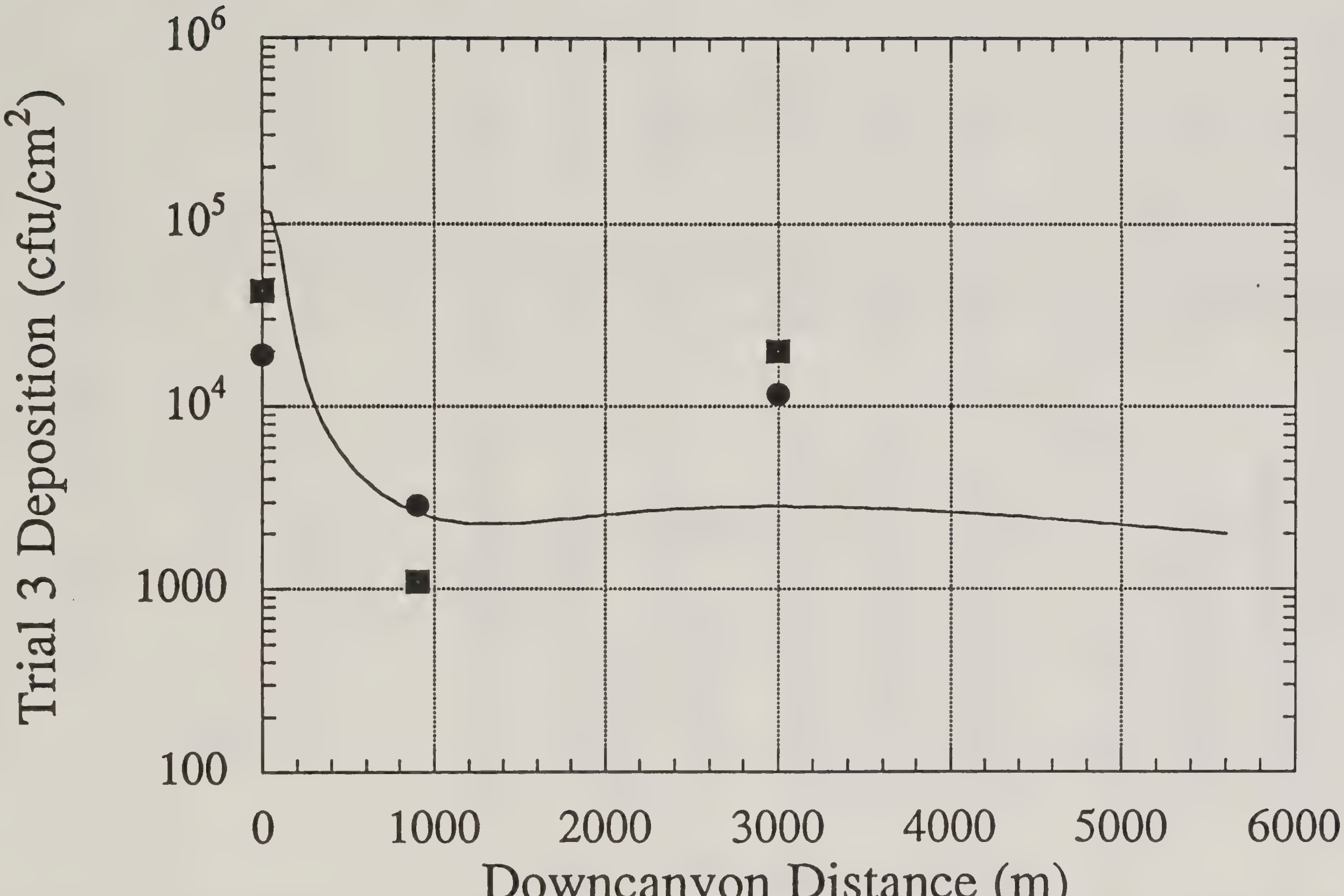

Figure 10b. 1993 Utah study Trial 3 -- downcanyon distance comparison between deposition data (cliffrose -- circles; buckwheat -- squares) and prediction (FSCBG -- solid line).

Table 4. Statistical comparison of sampler recoveries to FSCBG predictions, logarithmic least squares slope and intercept, and correlation coefficient, combined over all three trials of each study year (cfu refers to Bt colony forming units).

Year	Sampler Type	Slope	Intercept	R^2
1991	Spinning Rotorods vs FSCBG dosage (cfu-min/L)	0.237	3.240	0.748
	Wagner Samplers vs FSCBG dosage (cfu-min/L)	0.362	2.952	0.637
	Mylar Samplers vs FSCBG deposition (cfu/cm^2)	0.366	2.165	0.634
1992	Spinning Rotorods vs FSCBG dosage (cfu-min/L)	0.075	4.276	0.025
	Mylar Samplers vs FSCBG deposition (cfu/cm^2)	0.185	3.206	0.157
	Gambel Oak Foliage vs FSCBG deposition (cfu/cm^2)	0.297	2.814	0.376
1993	Spinning Rotorods vs FSCBG dosage (cfu-min/L)	0.270	3.392	0.676
	Mylar Samplers vs FSCBG deposition (cfu/cm^2)	0.5077	1.761	0.447
	Gambel Oak Foliage vs FSCBG deposition (cfu/cm^2)	0.184	2.855	0.112

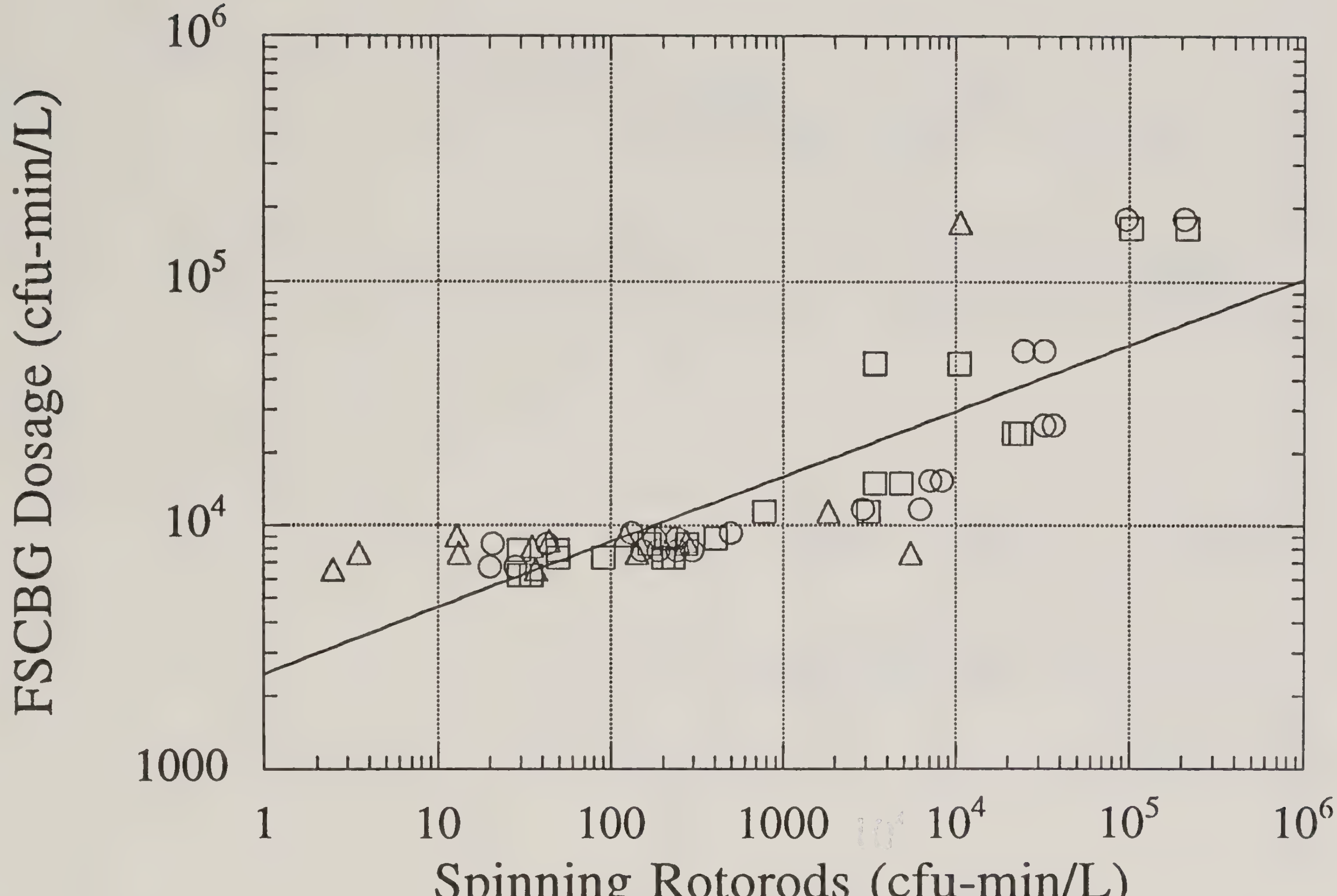

Figure 11. 1993 Utah study -- comparison between average spinning Rotorods and FSCBG dosage prediction at all downcanyon sampling stations: Trial 1 data denoted by circles; Trial 2 data by squares; and Trial 3 data by triangles. The solid line is the logarithmic least squares straight line through the data, with a correlation coefficient of 0.676.

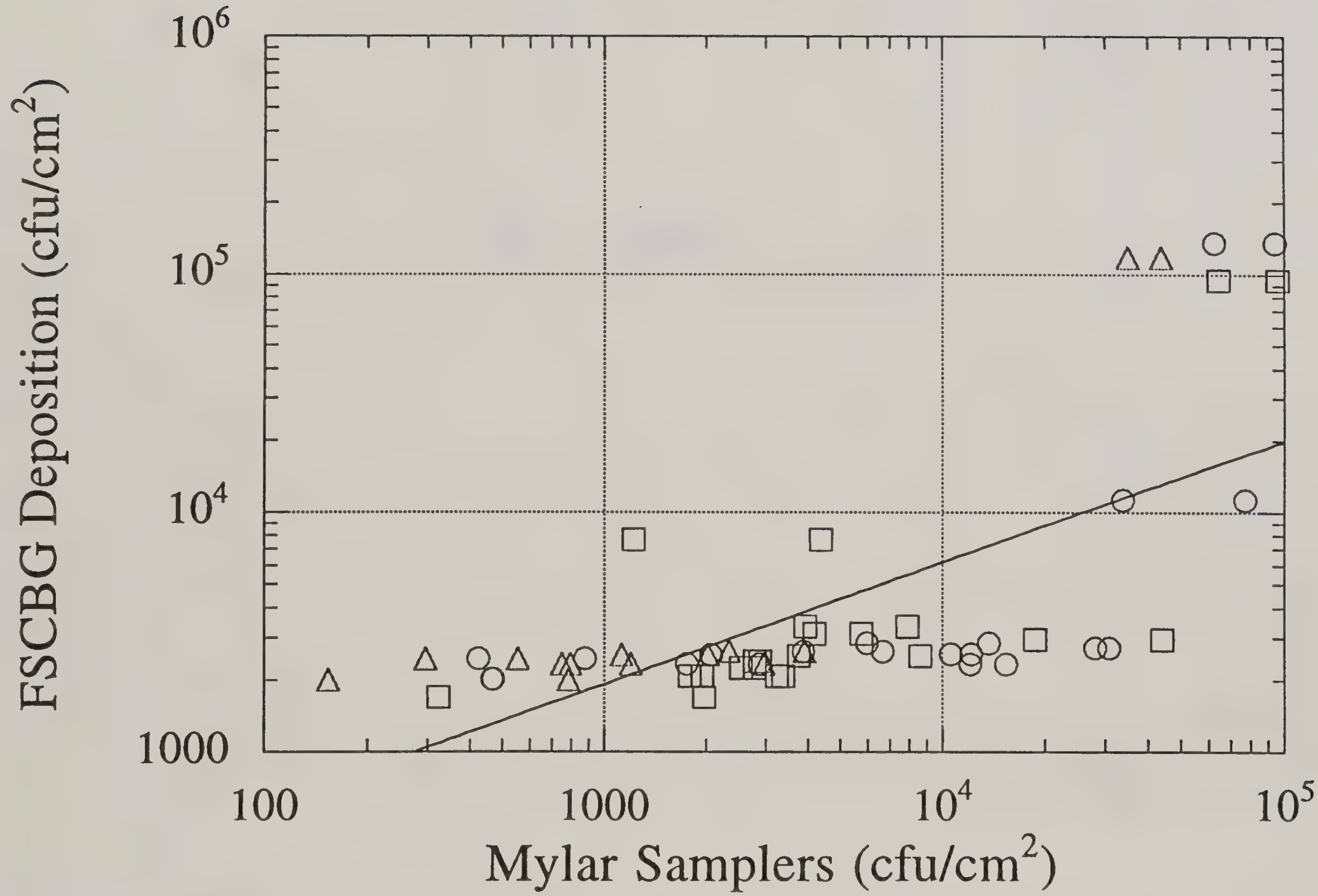

Figure 12. 1993 Utah study -- comparison between average Mylar samplers and FSCBG deposition prediction at all downcanyon sampling stations: Trial 1 data denoted by circles; Trial 2 data by squares; and Trial 3 data by triangles. The solid line is the logarithmic least squares straight line through the data, with a correlation coefficient of 0.447.

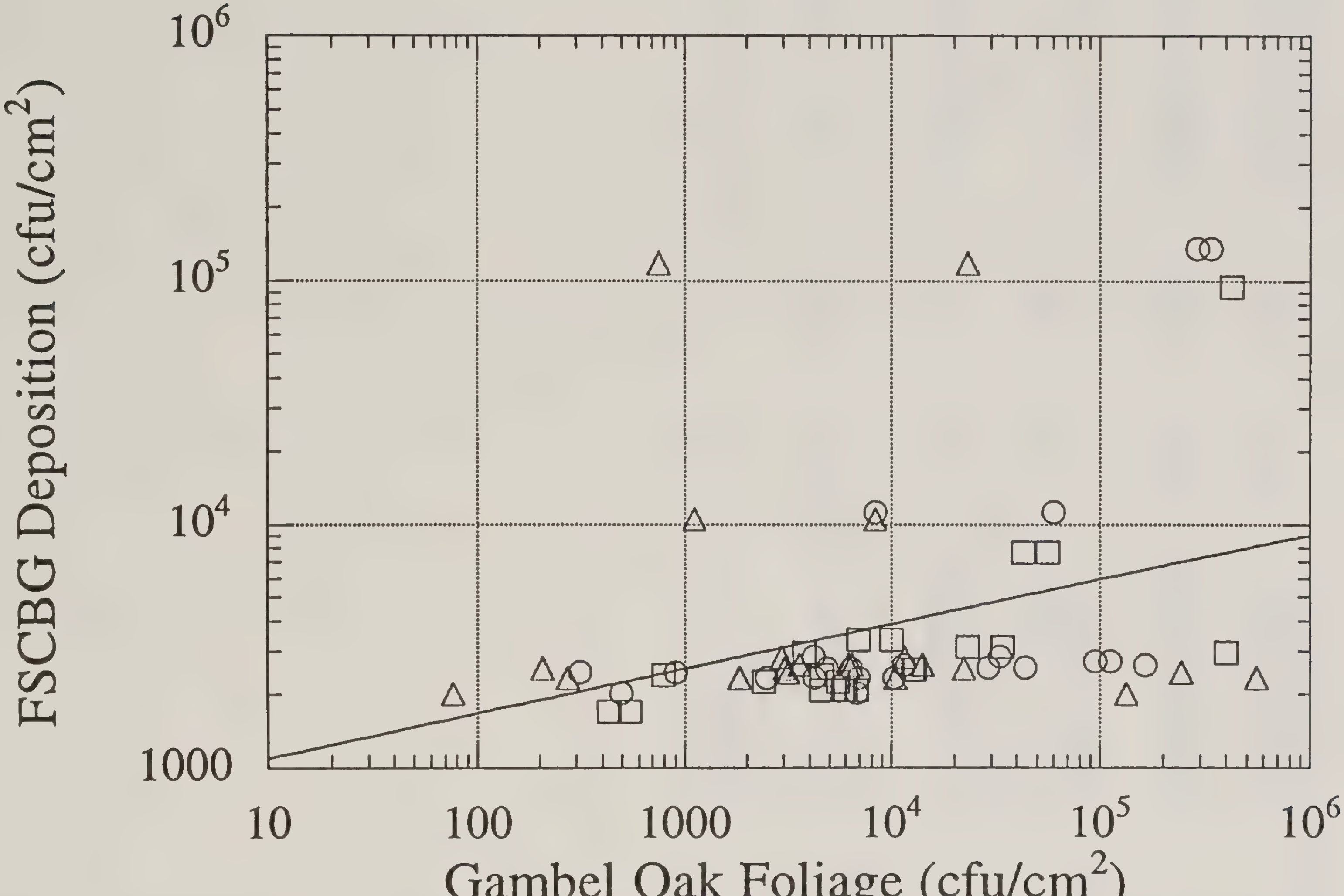

Figure 13. 1993 Utah study -- comparison between average Gambel oak foliage and FSCBG deposition prediction at all downcanyon sampling stations: Trial 1 data denoted by circles; Trial 2 data by squares; and Trial 3 data by triangles. The solid line is the logarithmic least squares straight line through the data, with a correlation coefficient of 0.112.

Table 5. Relative standard deviations of FSCBG predictions compared to average sampler recoveries.

Year	Sampler Type	Trial 1	Trial 2	Trial 3	Combined
1991	Spinning Rotorods and Wagner Samplers vs FSCBG dosage	0.736	0.690	0.599	0.679
	Mylar Samplers vs FSCBG deposition	0.642	0.589	0.680	0.638
1992	Spinning Rotorods vs FSCBG dosage	0.975	0.855	0.917	0.935
	Mylar Samplers and Gambel Oak Foliage vs FSCBG deposition	0.695	0.848	0.650	0.728
1993	Spinning Rotorods vs FSCBG dosage	0.742	0.801	0.920	0.808
	Mylar Samplers and Gambel Oak Foliage vs FSCBG deposition	0.404	0.478	0.577	0.549

Table 6. Least squares straight-line slope between the average sampler data and FSCBG predictions.

Year	Sampler Type	Trial 1	Trial 2	Trial 3
1991	Spinning Rotorods and Wagner Samplers vs FSCBG dosage	1.87	3.01	1.21
	Mylar Samplers vs FSCBG deposition	0.34	0.07	0.09
1992	Spinning Rotorods vs FSCBG dosage	6.44	3.16	6.67
	Mylar Samplers and Gambel Oak Foliage vs FSCBG deposition	5.16	11.27	1.34
1993	Spinning Rotorods vs FSCBG dosage	1.05	0.94	13.12
	Mylar Samplers and Gambel Oak Foliage vs FSCBG deposition	0.68	0.55	1.47

5. 1991 AND 1992 STUDY COMPARISONS

For completeness we include here the revised 1991 FSCBG predictions (with the corrected volatile fraction), and the 1992 FSCBG predictions (from Teske 1995a), in Figures 14 to 19 and 20 to 25, respectively. The volatile fraction appears to have a marginal effect on the prediction, which suggests that the larger drops deposit closer to the spray block, and the smaller drops remain aloft downcanyon, with drop size not being a factor.

The 1991 plots shown here are quite consistent with the plots presented in Barry et al. (1993a). Dosage is closely predicted to 1.5 km downcanyon, then overpredicted to the end of the sampler stations at 3 km. Deposition is predicted quite well for Trial 2 (Figure 18), underpredicted beyond 1 km in Trial 1 (Figure 17), and underpredicted by one order of magnitude throughout Trial 3 (Figure 19). The reasons cited for these differences (in Barry et al. 1993a) include the inability of the model to consider cloud dispersion and growth characteristics downcanyon, and the presence of undocumented upper air conditions existing in Parley's Canyon during the field study.

The 1992 data comparisons (Figures 20 to 25) show a decided underprediction of dosage for all three trials, and a bounding prediction of deposition, somewhat more consistent in Trial 3 (Figure 25). The reason given in Teske (1995a) for these differences lies in the observation that the spray clouds did not move down the middle of the canyon (where the samplers were located and the predictions were made), but were again affected by meteorological patterns above Lamb's Canyon. It is anticipated that VALDRIFT would account for this effect.

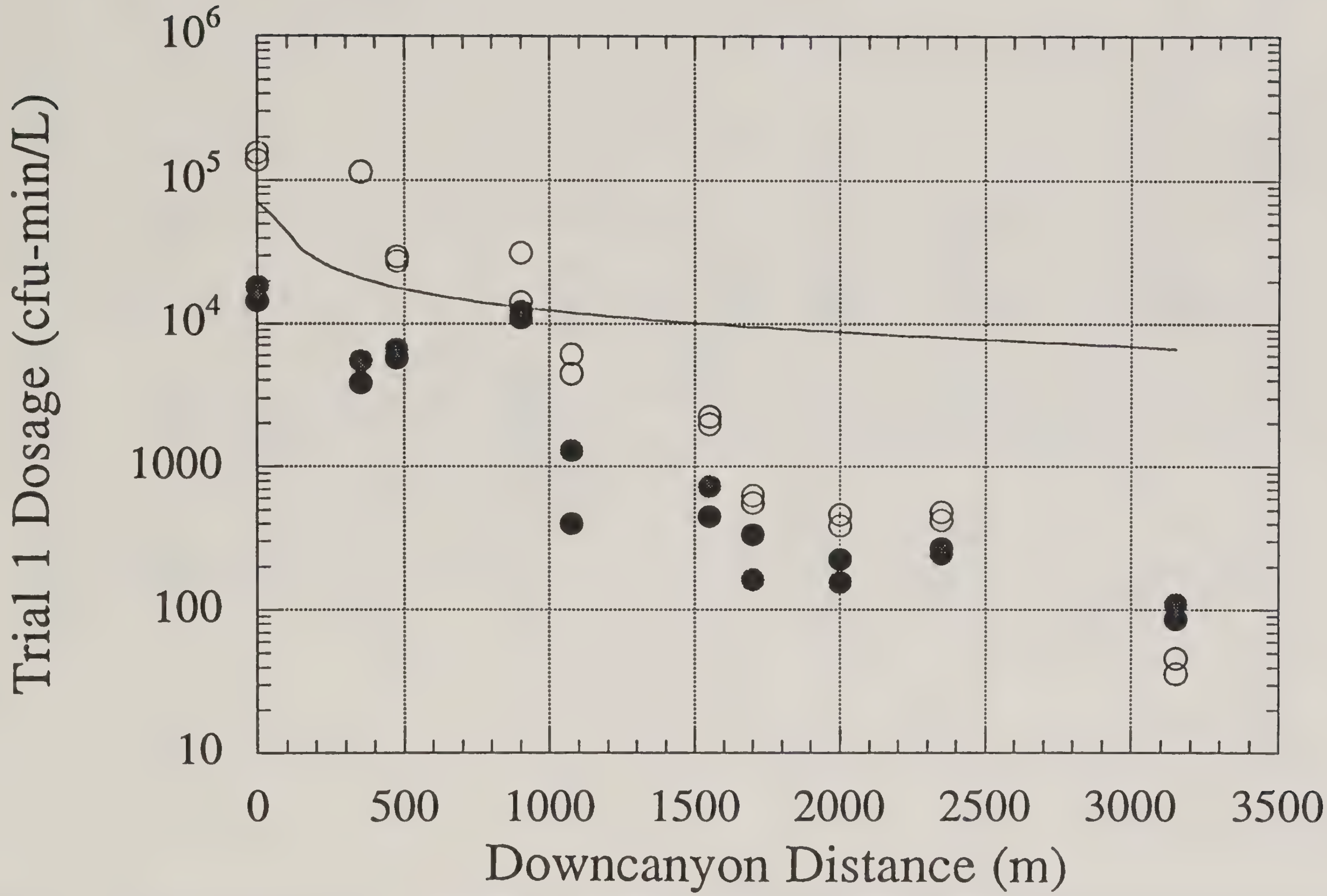

Figure 14. 1991 Utah study Trial 1 -- downcanyon distance comparison between dosage data (spinning Rotorods -- circles; and Wagner samplers -- closed circles) and prediction (FSCBG -- solid line).

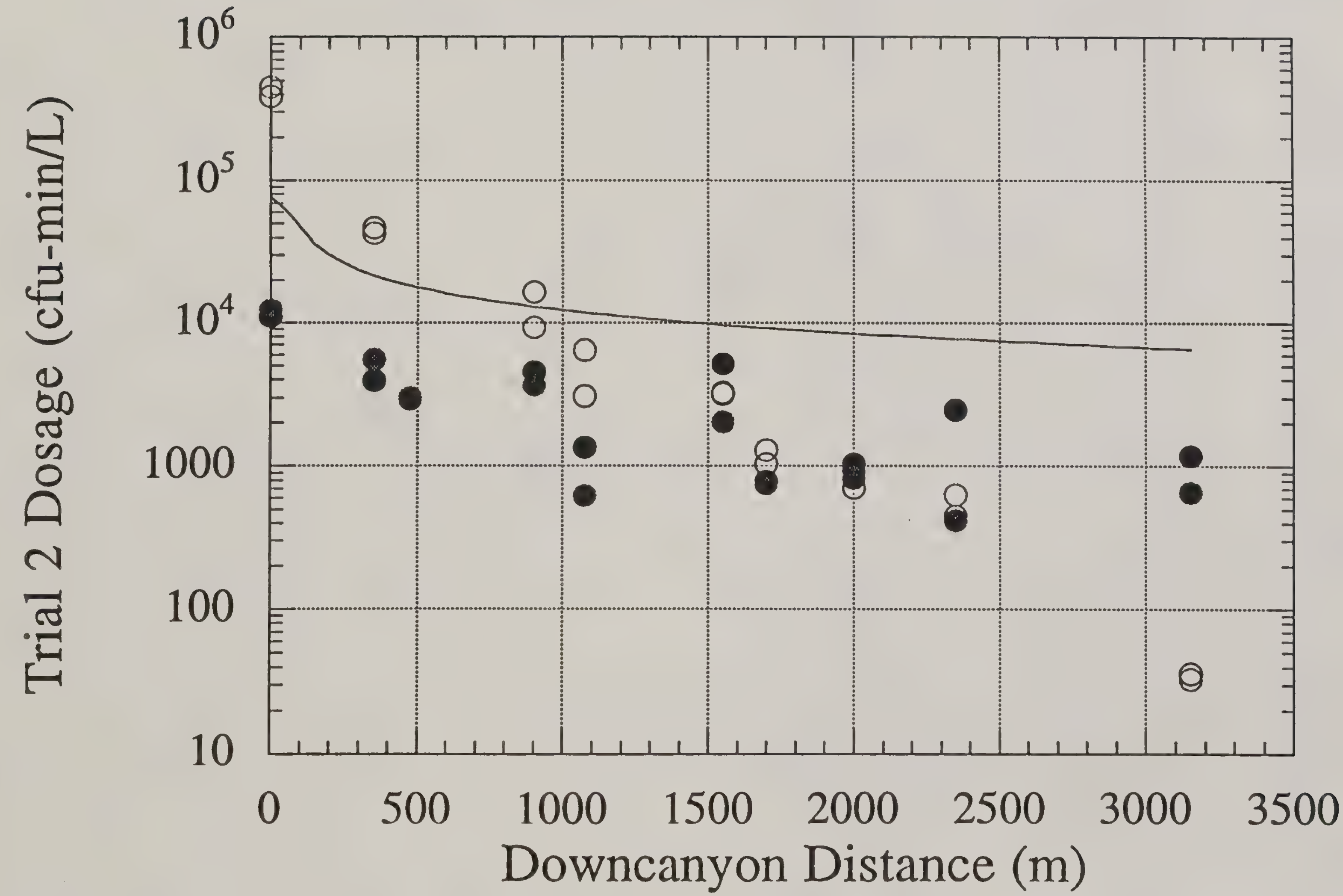

Figure 15. 1991 Utah study Trial 2 -- downcanyon distance comparison between dosage data (spinning Rotorods -- circles; and Wagner samplers -- closed circles) and prediction (FSCBG -- solid line).

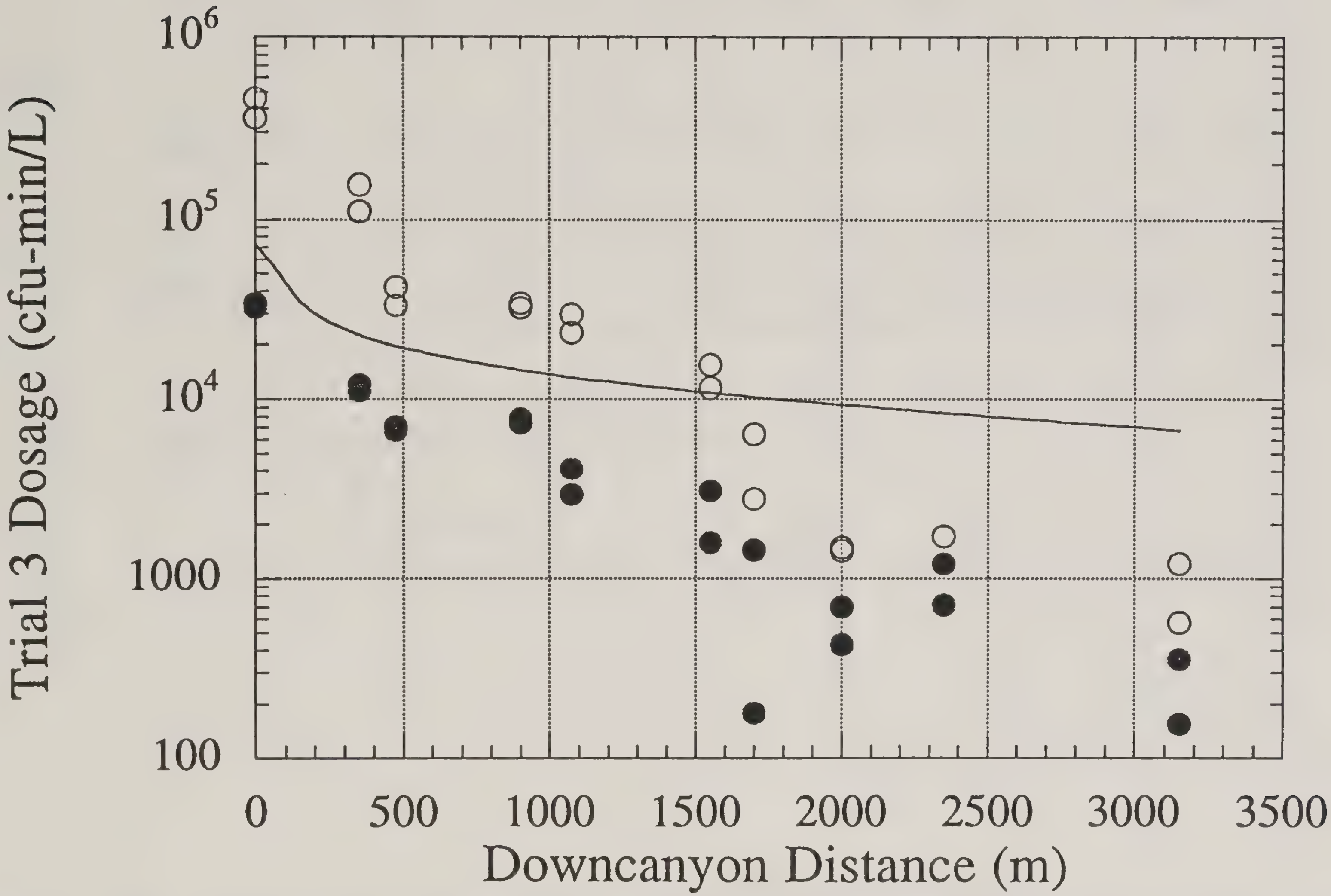

Figure 16. 1991 Utah study Trial 3 -- downcanyon distance comparison between dosage data (spinning Rotorods -- circles; and Wagner samplers -- closed circles) and prediction (FSCBG -- solid line).

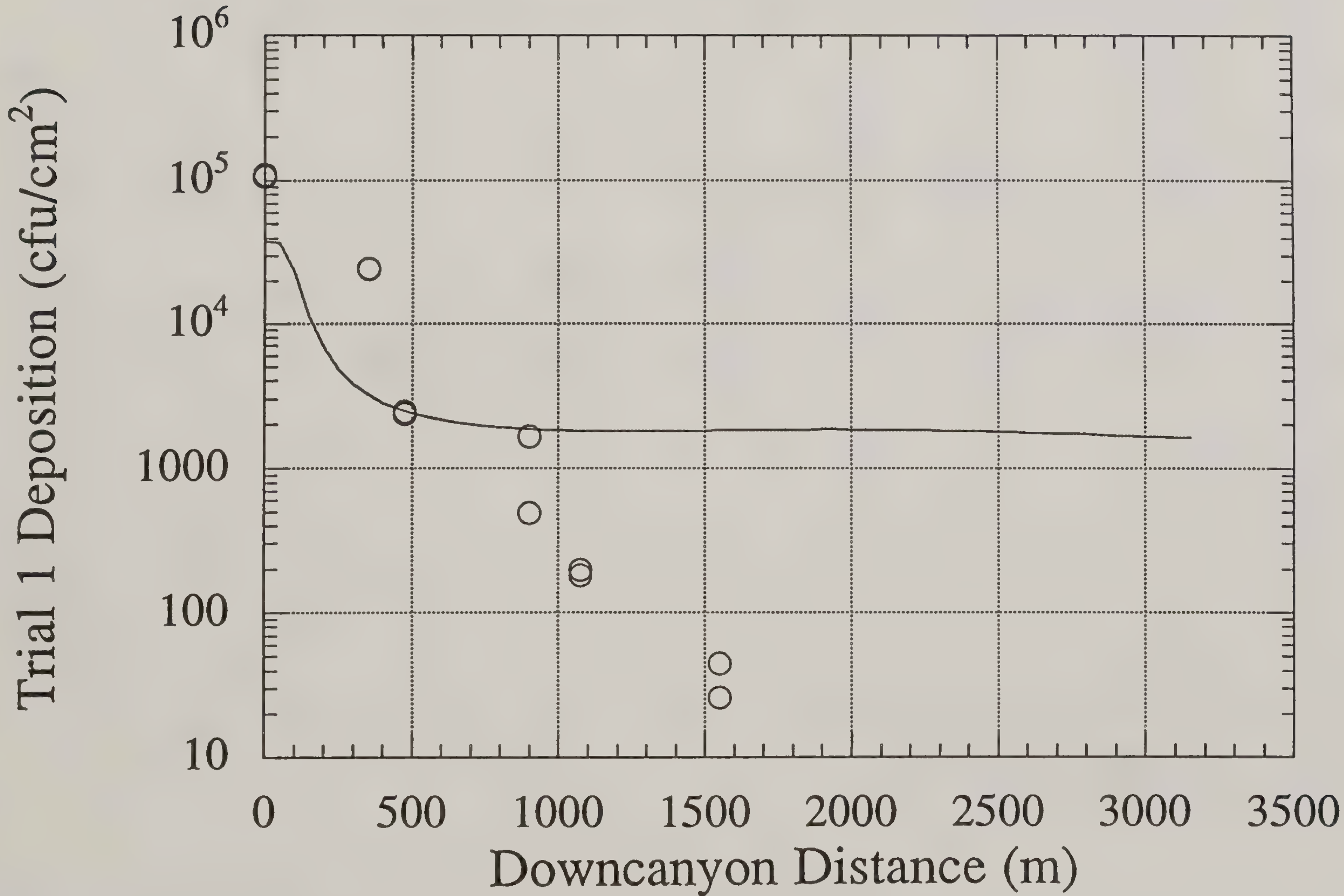

Figure 17. 1991 Utah study Trial 1 -- downcanyon distance comparison between deposition data (Mylar samplers -- open circles) and prediction (FSCBG -- solid line).

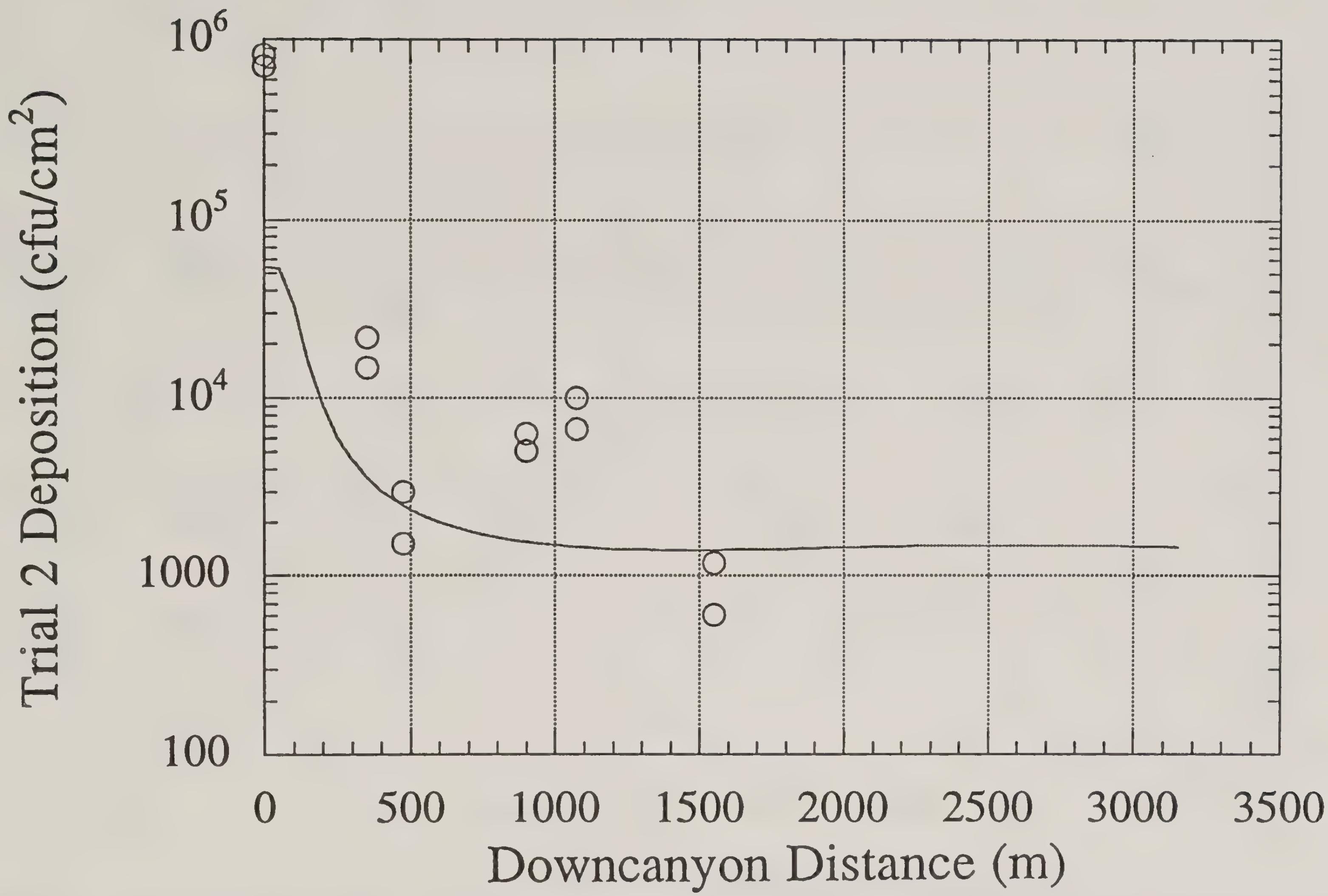

Figure 18. 1991 Utah study Trial 2 -- downcanyon distance comparison between deposition data (Mylar samplers -- open circles) and prediction (FSCBG -- solid line).

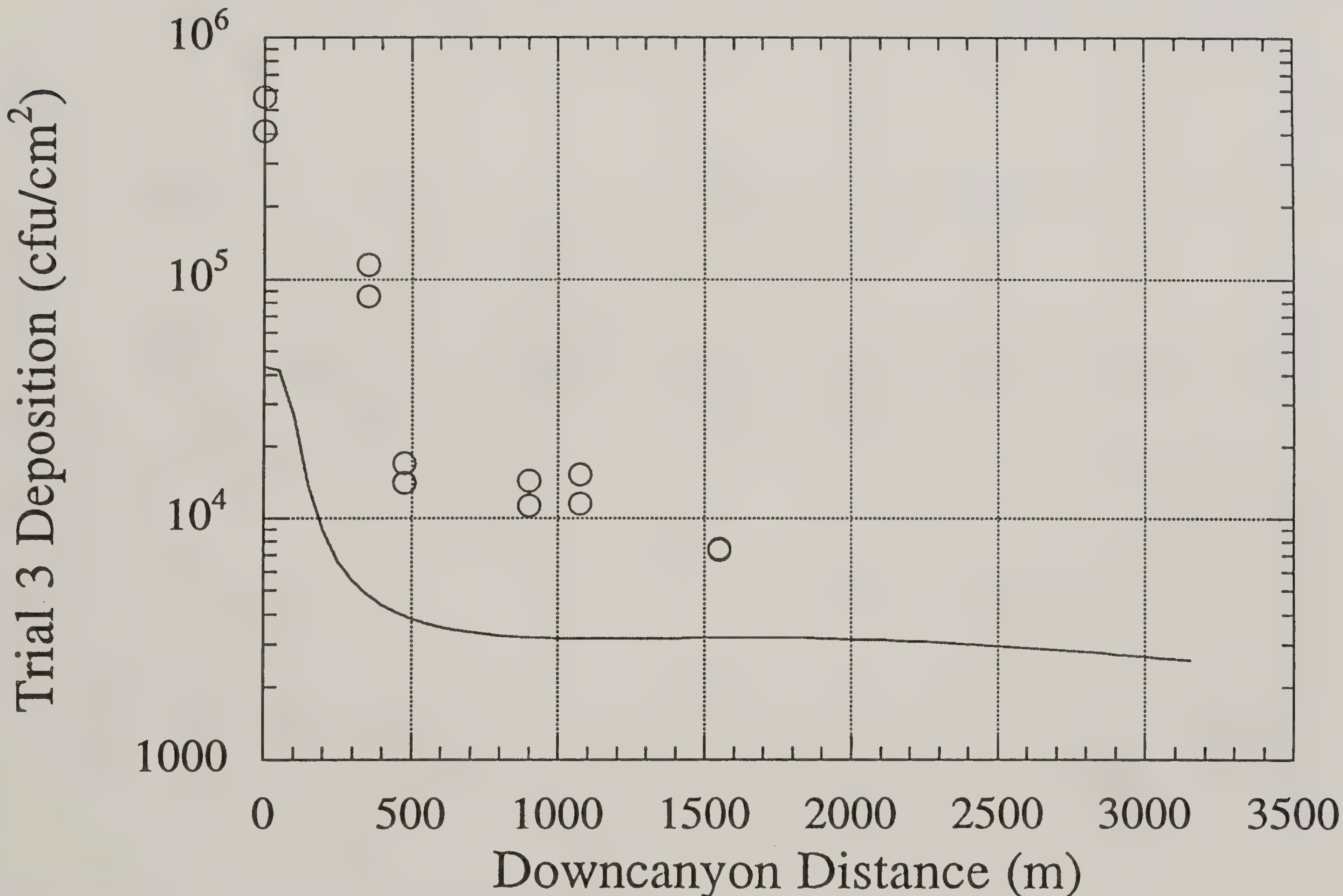

Figure 19. 1991 Utah study Trial 3 -- downcanyon distance comparison between deposition data (Mylar samplers -- open circles) and prediction (FSCBG -- solid line).

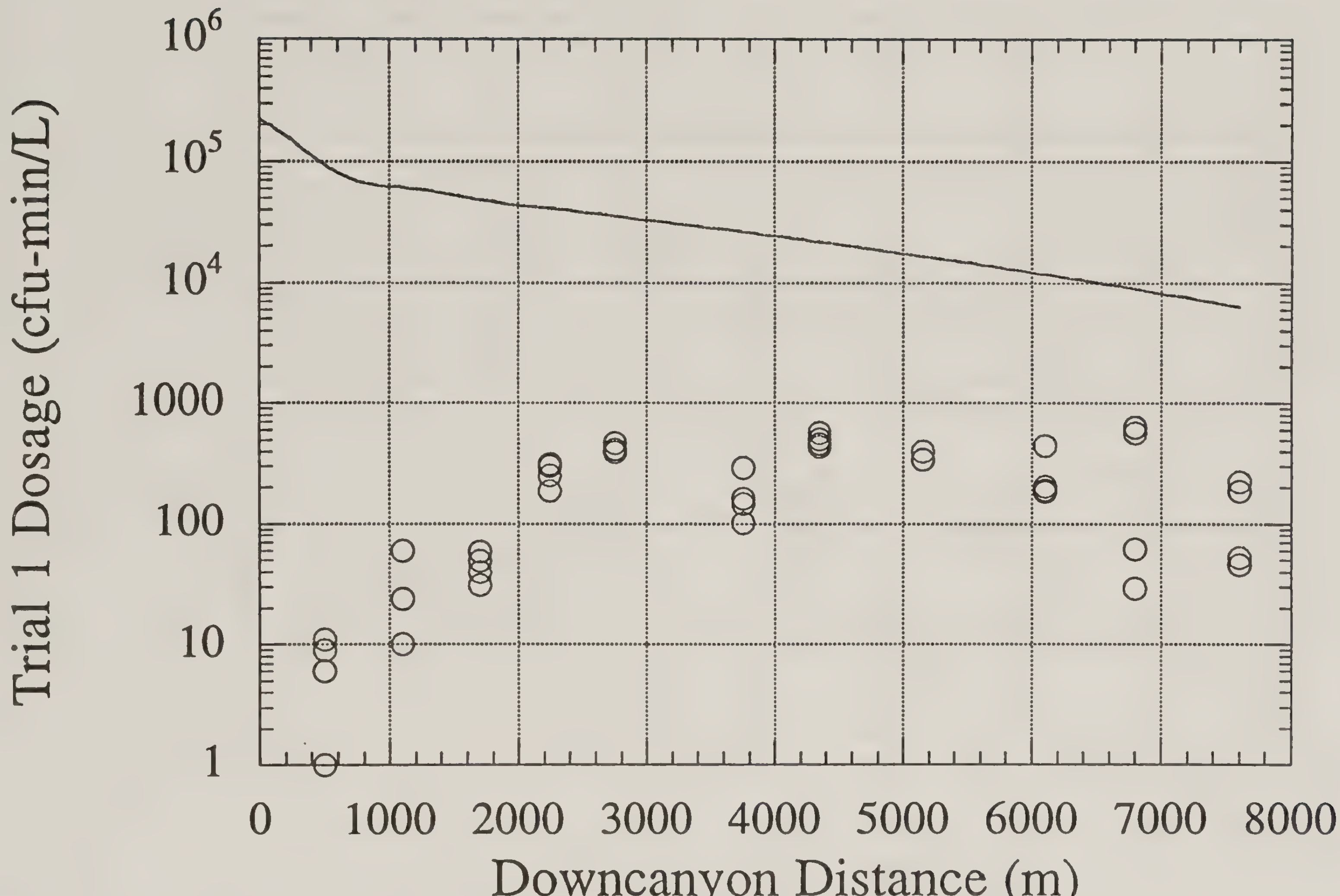

Figure 20. 1992 Utah study Trial 1 -- downcanyon distance comparison between dosage data (spinning Rotorods -- circles) and prediction (FSCBG -- solid line).

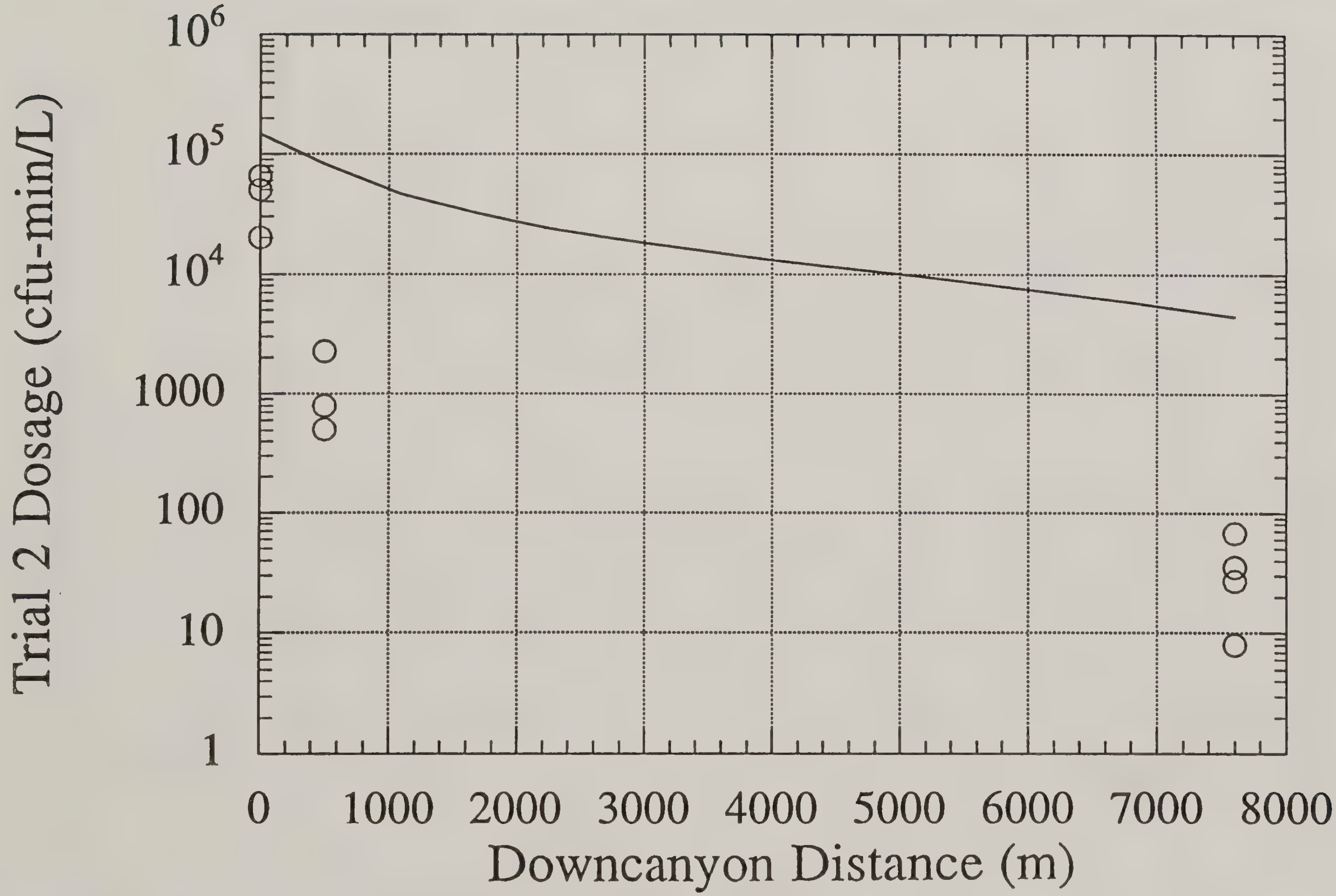

Figure 21. 1992 Utah study Trial 2 -- downcanyon distance comparison between dosage data (spinning Rotorods -- circles) and prediction (FSCBG -- solid line).

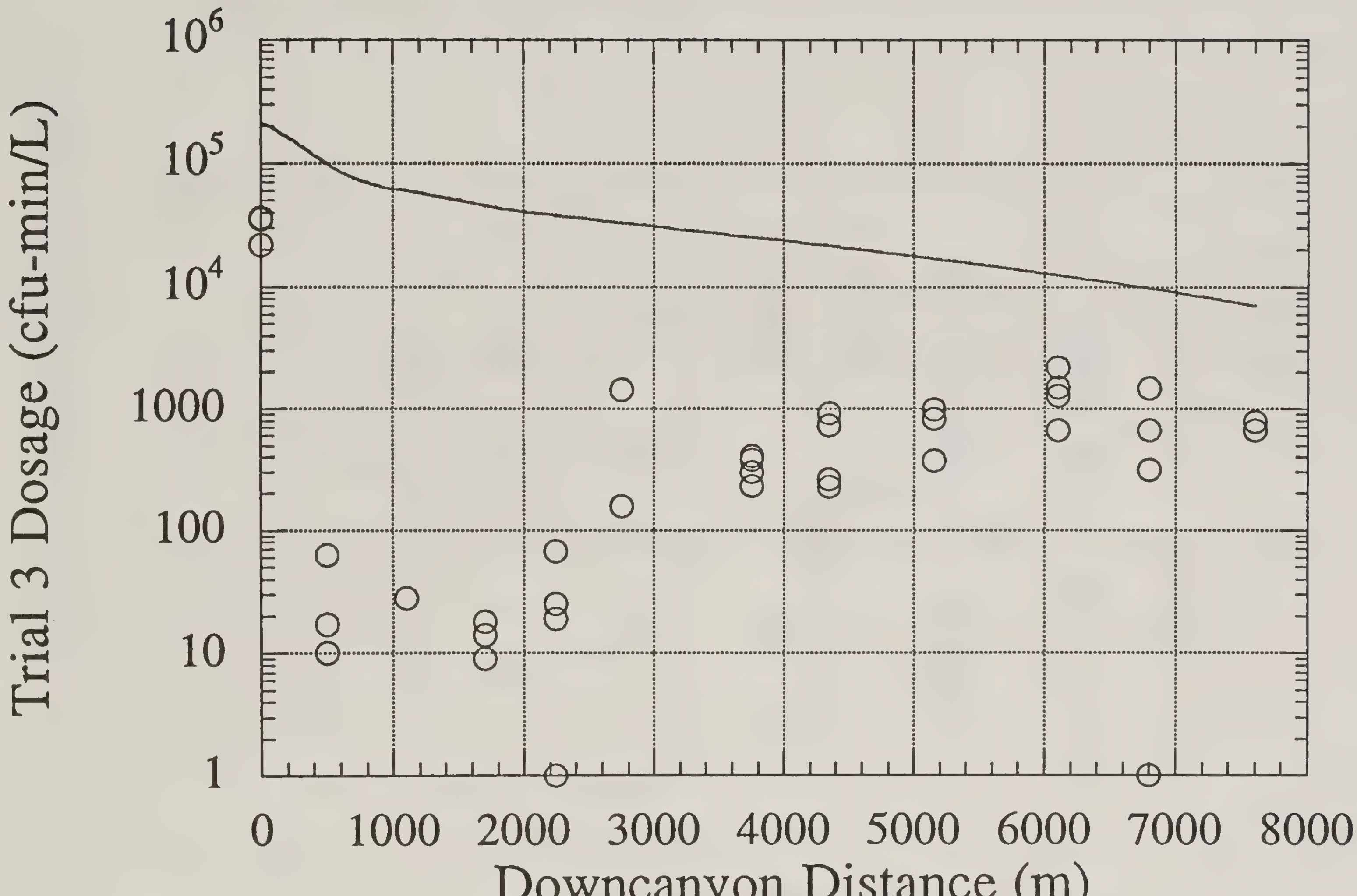

Figure 22. 1992 Utah study Trial 3 -- downcanyon distance comparison between dosage data (spinning Rotorods -- circles) and prediction (FSCBG -- solid line).

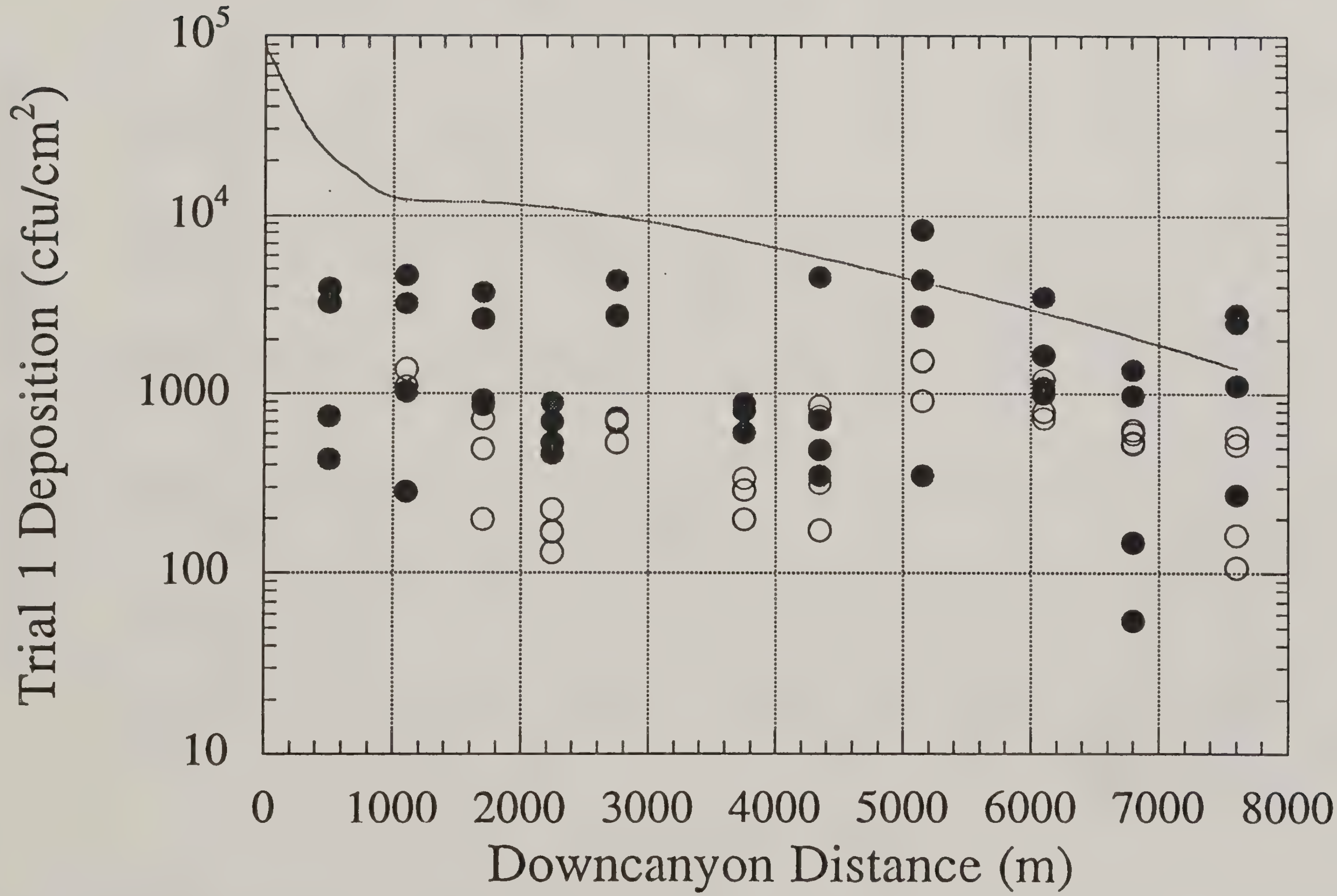

Figure 23. 1992 Utah study Trial 1 -- downcanyon distance comparison between deposition data (Mylar samplers -- open circles; and Gambel oak foliage -- closed circles) and prediction (FSCBG -- solid line).

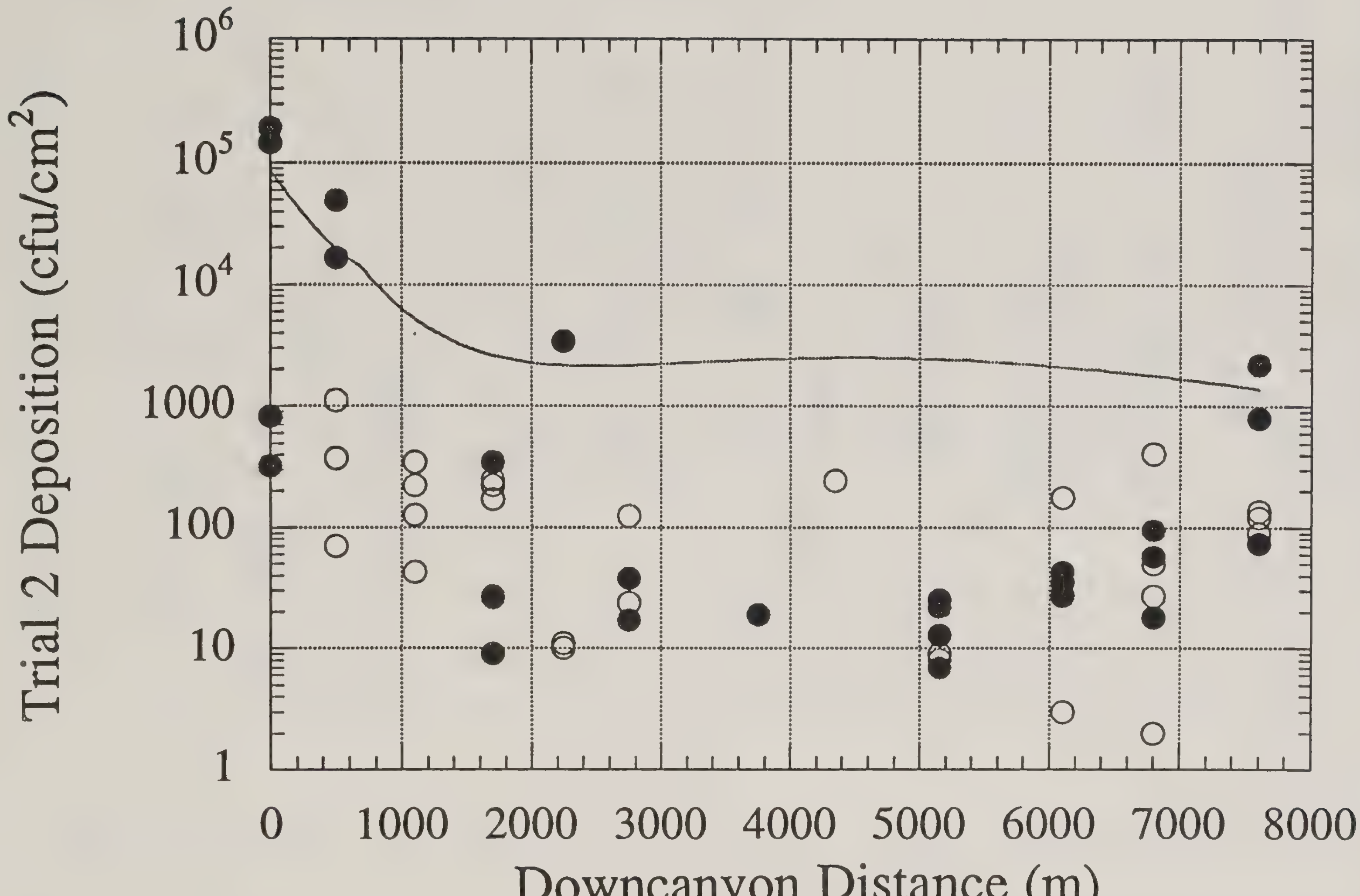

Figure 24. 1992 Utah study Trial 2 -- downcanyon distance comparison between deposition data (Mylar samplers -- open circles; and Gambel oak foliage -- closed circles) and prediction (FSCBG -- solid line).

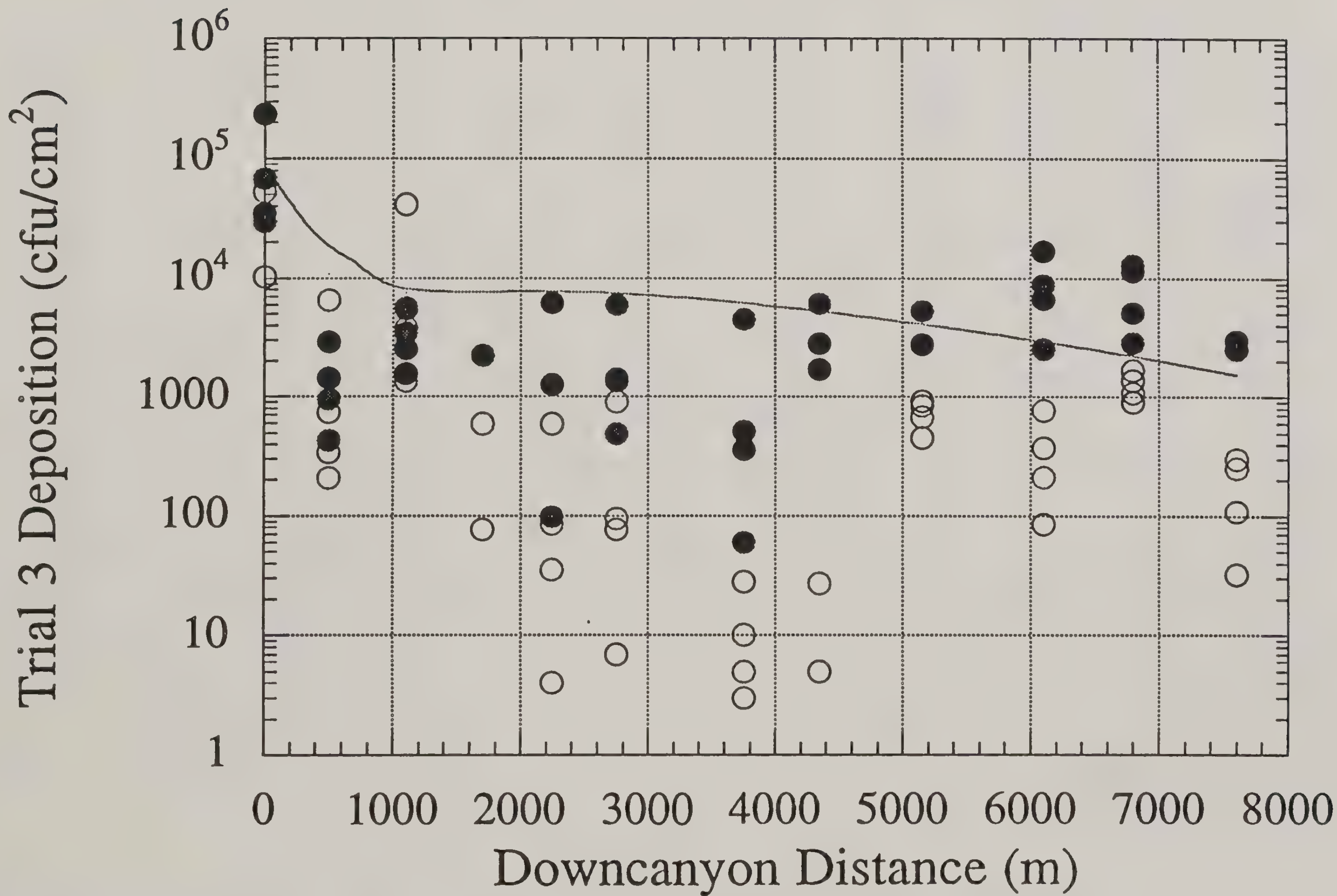

Figure 25. 1992 Utah study Trial 3 -- downcanyon distance comparison between deposition data (Mylar samplers -- open circles; and Gambel oak foliage -- closed circles) and prediction (FSCBG -- solid line).

6. DATA SUMMARY

Tables 7 to 10 compile the raw data from the three field trials conducted in 1993. FSCBG model predictions are included where they apply.

Table 7. Spinning Rotorod data (with FSCBG dosage predictions). Data includes duplicate paired samples (1 and 2) collected at both lateral locations A and B at each downcanyon distance. Dosage is expressed in cfu-min/L of Bt. Data loss is denoted by "-".

Downcanyon Distance (m)	Spinning Rotorod Data A1	A2	B1	B2	FSCBG Prediction
Trial 1					
0	86944	105278	208056	206667	179273
300	21806	27222	36806	27778	52133
900	37083	27917	32500	41111	25996
2000	7097	-	9472	7139	15385
3000	2833	2931	6181	-	11696
4000	481	510	165	98	9318
4250	256	226	181	-	8832
4800	301	294	329	156	7878
4500	23	18	44	41	8380
4800	275	26	325	54	7878
5600	39	17	9	31	6727
Trial 2					
0	135139	70833	343194	85139	164806
300	10458	-	431	6333	46327
900	21111	26111	31250	11889	24174
2000	3389	3389	5153	4583	14993
3000	1138	417	2486	3792	11360
4000	322	489	-	210	8857
4250	436	117	126	206	8348
4800	167	236	54	127	7359
4500	26	33	40	58	7878
4800	188	272	65	34	7359
5600	46	23	26	33	6186
Trial 3					
0	7278	14028	-	-	174265
300	-	-	-	-	49987
900	-	-	-	-	25123
2000	-	-	-	-	14920
3000	-	-	-	1819	11360
4000	2	23	121	-	9056
4250	48	39	275	-	8584
4800	260	24	6	1	7658
4500	-	-	18	52	8145
4800	-	5458	6	20	7658
5600	2	-	42	31	6539

Table 8. Mylar sampler data (with FSCBG deposition predictions). Data includes duplicate paired samples (1 and 2) collected at both lateral locations A and B at each downcanyon distance. Deposition is expressed in cfu/cm^2 of Bt. Data loss is denoted by "-".

Downcanyon Distance (m)	Mylar Sampler Data A1	A2	B1	B2	FSCBG Prediction
Trial 1					
0	93716	-	55556	69217	135908
300	76685	-	-	33789	11281
900	5883	50091	26776	35064	2739
2000	11384	9745	10838	13479	2564
3000	12933	14390	5874	6066	2842
4000	4727	3060	6621	6712	2638
4250	2013	2149	1603	2514	2550
4800	2104	1412	2933	2814	2336
4500	425	-	875	-	2455
4800	15337	-	12040	-	2336
5600	470	-	465	-	2017
Trial 2					
0	60383	68306	87978	103734	94452
300	417	2031	4417	4326	7654
900	44991	42896	17031	20401	2963
2000	3934	3953	4554	11202	3359
3000	4135	4253	5264	6257	3115
4000	3342	4199	8934	8297	2535
4250	2623	3179	2741	2842	2388
4800	1958	-	2186	1393	2083
4500	3333	2250	2295	2769	2245
4800	4217	2541	3233	3233	2083
5600	372	277	3534	418	1699
Trial 3					
0	37341	32332	45082	42259	117390
300	-	-	-	-	10501
900	-	-	-	-	2630
2000	-	-	-	-	2545
3000	-	-	-	-	2836
4000	1211	3479	3916	-	2633
4250	2204	1840	628	1621	2544
4800	947	636	1211	290	2329
4500	266	328	437	671	2449
4800	3333	2605	434	1958	2329
5600	104	204	529	1038	2009

Table 9. Gambel oak foliage data (with FSCBG deposition predictions). Data includes both lateral locations A and B at each downcanyon distance. Deposition is expressed in cfu/cm^2 of Bt. Data loss is denoted by "-".

Downcanyon Distance (m)	Gambel Oak Foliage Data A	B	FSCBG Prediction
Trial 1			
0	290918	337139	135908
300	59551	8366	11281
900	94498	111842	2739
2000	29090	43573	2564
3000	4201	32919	2842
4000	163690	11364	2638
4250	4835	6381	2550
4800	6882	2478	2336
4500	313	900	2455
4800	10273	4213	2336
5600	495	6775	2017
Trial 2			
0	-	424490	94452
300	43024	56445	7654
900	3789	401562	2963
2000	6901	9927	3359
3000	33863	23041	3115
4000	12866	12630	2535
4250	4588	793	2388
4800	5800	4543	2083
4500	5513	2414	2245
4800	5952	6744	2083
5600	432	540	1699
Trial 3			
0	23226	747	117390
300	8371	1111	10501
900	6181	6394	2630
2000	22272	-	2545
3000	2948	11538	2836
4000	14075	3571	2633
4250	205	3032	2544
4800	10410	273	2329
4500	3171	243581	2449
4800	1842	558079	2329
5600	133901	76	2009

Table 10. Non-target Lepidoptera data (with FSCBG deposition predictions) for both species at each downcanyon distance. Deposition is expressed in cfu/cm^2 of Bt. Data loss is denoted by "-".

Downcanyon Distance (m)	Non-Target Lepidoptera Data Cliffrose	Buckwheat	FSCBG Prediction
Trial 1			
0	347300	105300	135908
300	11000	-	11281
900	20200	14300	2739
2000	300	-	2564
3000	8300	11700	2842
Trial 2			
0	281400	2864	94452
300	33500	-	7654
900	81400	55600	2963
2000	8400	-	3359
3000	16400	3700	3115
Trial 3			
0	19100	42500	117390
300	-	-	10501
900	2900	1100	2630
2000	-	-	2545
3000	11700	20000	2836

7. CONCLUSIONS

This memorandum compares Gambel oak foliage and physical sampler types, with FSCBG model dosage and deposition predictions, for the Utah 1993 study of Bt drift. The 1991 study predictions are reworked to correct an error in volatile fraction (with slight changes in previous results), and the 1992 study predictions are included for completeness. An overall comparison suggests that FSCBG does a representative job of predicting a decidedly complex terrain scenario, with its predictions breaking down just as downcanyon meteorology and topography become important.

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